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TM 5-244

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

MULTIPLEX MAPPING

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HEADQUARTERS, DEPARTMENT OF THE ARMY

MAY

ACKNOWLEDGEMENT

Acknowledgment is made to United States Geological Survey for material contained in this manual; and to the Central States Forest Experiment Station, United States Forest Service, for 1 and 2, figure 35.

TECHNICAL MANUAL }
No. 5-244 }

HEADQUARTERS,
DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C., *16 May 1962*

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***This manual supersedes TM 5-244, 16 June 1954.**

CHAPTER 1

THEORY OF MULTIPLEX

1. Purpose

This manual serves as a guide for the operation of multiplex stereoscopic mapping equipment and for the employment of this equipment in the preparation of topographic map manuscripts.

2. Scope

a. This manual covers the theory, equipment, and techniques used in the multiplex method of mapping. It describes the equipment, explains the fundamental principles, gives detailed instructions for operating the equipment, and discusses attainable accuracies. A glossary of technical terms is included. This manual does not compare the merits of the multiplex method of mapping with other methods. TM 5–231 contains information needed to plan and execute a mapping project.

b. Users of this manual are encouraged to submit comments or recommendations for changes to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment to insure understanding and proper evaluation. Comments should be forwarded directly to the Commandant, U.S. Army Engineer School, Fort Belvoir, Va.

c. Information contained herein is applicable without modification to both nuclear and nonnuclear warfare.

3. Development

a. At first the use of aerial photographs for mapping was confined to obtaining planimetric information. This led to the use of large-coverage, multiple-lens cameras to plot additional control and to fill in planimetric detail by the radial line method. Stereoscopic viewing of overlapping pairs of photographs was used only in studying the terrain, because no method was then available in this country for precise measurements using stereoscopic models.

b. Multiplex equipment was eventually adopted for military mapping compilations of high accuracy. The first multiplex equipment procured for military use was designed around the camera equipment then used by the Army Air Corps. The angle of coverage of mapping cameras used at that time was approximately 70°. This angle of coverage became known as a *normal* angle. Earliest multiplex equipment was therefore known as *normal* equipment. The development of cameras to cover wider angles continued and subsequently produced a camera that covered approximately 93°. This angle of coverage became known as *wide-angle*. In time, the wide-angle multiplex equipment made other equipment obsolete. Further references to multiplex equipment or techniques in this manual pertain to wide-angle equipment and techniques, unless otherwise stated.

Safety Note. Certain procedures described in this manual utilize equipment and chemicals which, if used without certain precautions, may present hazards to operating personnel. To avoid accidents which might injure personnel or the delicate equipment used in this field, supervisory and operating personnel must always be conscious of those factors which might pose likely areas of trouble.

4. Stereoscopic Mapping

a. Within certain limits, a stereoscopic view of any subject consists of two pictures of the subject which are taken from slightly different positions and mentally fused into one view. However, this view or "model" is generally not a true-to-scale reproduction of the subject. Each picture is a perspective view of the subject, the camera lens being the perspective center. To have a true perspective, one of the following must prevail: the taking lens must be without distortion or the inherent distortions must be corrected by some means; the picture must be viewed through the taking lens; or the picture must be viewed through a lens exactly like the taking lens. To obtain a correct stereoscopic model, two perspective views must be fused with exactly the same angular relationship that existed when the pictures were taken. This means the taking position and orientation of each picture must be recovered. Absolute recovery is not possible by any system of direct measurement.

b. A true stereoscopic model is formed from two correct perspective views by projecting the pictures from the same or similar cameras so that all rays from corresponding picture points intersect. To project the proper image formation and to obtain a model that can be used for mapping, the following requirements are paramount:

(1) Preparing an original transparent positive (diapositive) that does not appreciably change size, by using glass plate.

(2) Projecting an image which duplicates exactly the optical properties of the taking camera at the required scale.

(3) Orienting the two projections, precisely with relation to each other (relative orientation) and adjusting the positions of points to their absolute positions as determined by the control net (absolute orientation).

(4) Viewing the double projection without changing this orientation.

(5) Making measurements within the stereoscopic model.

c. There are several methods of fulfilling the above requirements. The multiplex method was adopted for military mapping after considering these factors: accuracy, simplicity, portability, operating speed, ease of obtaining and training operators, original cost, and operating cost.

5. Theory

The multiplex is a stereoscopic plotting instrument designed to reconstitute, in miniature, the geometric relationship between the ground, the lens, and the focal plane at the instant of exposure. Figure 1 shows the effect seen by the operator when these geometric relationships have been restored. The theory on which the multiplex is based was first demonstrated in France in 1858, but the application of the theory to map compilation is more recent, having to wait for the development of aircraft capable of carrying the camera and the development of the multiplex aeroprojector system for projecting the images. Stereoscopic views (par. 4) reconstitute for the viewer the three-dimensional effect of the original image. Various applications of this principle are now familiar in 3-D movies, advertising brochures, and comic books. Most of these applications are two-color (dichromatic) anaglyphs viewed through dichromatic filters. In some, the two colors are replaced by polarized imprints. But, whatever the specific medium used, the effect of three dimensional images is achieved by allowing each eye to see only one of a pair of images. When dichromatic images are projected and observed through dichromatic filters, the effect is, as shown in figure 1, that of a three dimensional "model." When a means of orienting this model is provided whereby distortions are removed and the model can be related to a base graphically constructed in conformance with control points, it is then possible to measure distances and elevations in the model with acceptable accuracy.

6. Optical Considerations

The lenses in aerial cartographic cameras are compound, consisting of two or more elements made of different kinds of glass, ground with different radii of curvature, and either cemented together or separated by an air space. When light rays travel from air into glass and from glass into air, as when passing through a lens, they are bent or refracted at an angle determined by the characteristics of the lens. The amount of refraction varies with the type of glass and the angle of incidence (entering angle) to

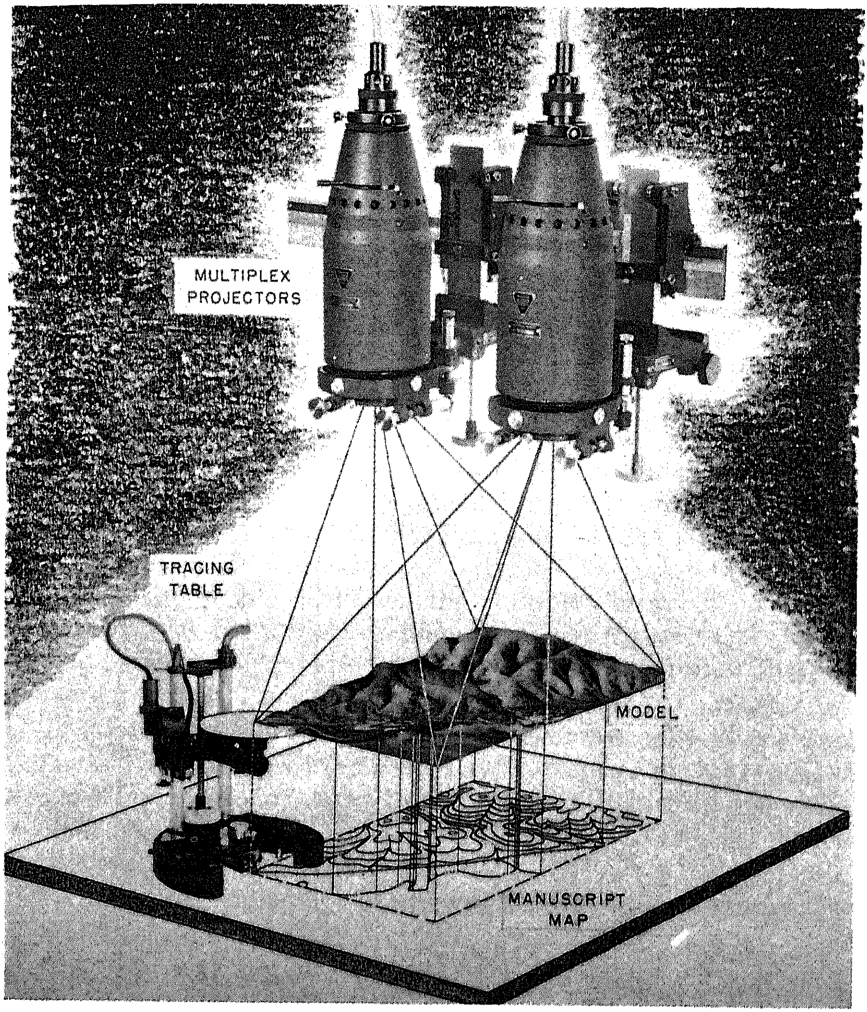

Figure 1. The effect of a three dimensional spatial model.

the lens surface. When parallel rays of light enter a well-designed and accurately constructed lens, they are bent so that they change direction and converge. For each lens there are two points at which the converging rays of light have identical geometric relationships. These two points are called *nodes* or *nodal points* and are further differentiated as *incident* node and *emergent* node. A ray of light emerging from the second (emergent) node is parallel to the ray incident at the first node. The distance measured along the lens axis from the rear (emergent) nodal point to the plane of best average definition over the entire field used in the aerial camera is referred to as the *equivalent focal length* of the lens used. The plane of best average definition is called the *focal plane* and is the plane in which images of points in the object field of the lens are focused. Figure 2 shows, schematically, these relationships.

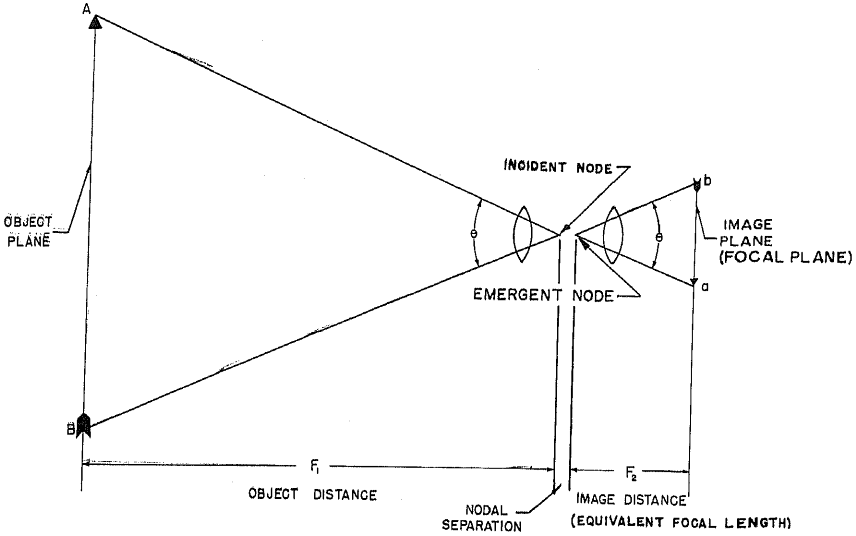

Figure 2. Geometric relationships.

7. Application of Multiplex Method

The multiplex is applicable to most mapping projects. It can be used in the preparation of maps at all scales and all contour intervals. The practical limits of scale and contour interval depend upon the altitude of photograph. With low altitude photography, scales as large as 1:3,000 with a contour interval as small as 5 feet can be compiled. Normal military missions at altitudes of 25,000 feet or higher require that plotting be performed at a scale of 1:20,000 or smaller, with a contour interval of at least 50 feet. The following is a broad generalization of the steps employed by the multiplex method in converting topographic detail from the aerial photographs to an orthogonal drawing. Thus, the contour interval, which is often the controlling factor, roughly determines the necessary flight height, and this in turn rather closely determines the model scale (which is the same as the compilation scale, except when a pantograph or other device is used for scale conversion). When referring to the flight height-contour interval relationship, the term "C-factor" is commonly used. By definition, this is the ratio of the flight height to the smallest contour interval that can be obtained from the instrument within the generally accepted standard of accuracy for topographic maps. In theory it should be possible to calculate the maximum C-factor for any stereoscopic plotting instrument when its various characteristics are known. However, in practice, the maximum C-factor cannot easily be determined because it is affected to such a large extent by other factors that have no particular connection with the plotting instrument itself. Some of these are: the amount and type of control, the accuracy standard to be complied with, the type of terrain, atmospheric conditions, quality of photography, and the likelihood of errors in other phases of the process. The actual C-factor used for compilation varies over wide limits for the same reason, and for other reasons, such as the necessity of planning flights within prescribed boundaries or the necessity of utilizing photography not specifically planned for a project. Based on experience, a value of 600 is generally considered to be a safe limiting value for the multiplex C-factor, under average conditions. Once the flight height is established, the multiplex model scale is governed solely by the projection distance of the multiplex projector, which distance can be varied only insofar as the depth of focus of the lens permits.

a. The multiplex method of mapping uses transparent positives (diapositives) prepared from negatives of aerial photographs. A reduction printer correlated to the optical qualities of the aerial camera lens produces corrected diapositives suitable for use in multiplex projectors.

b. The multiplex equipment recreates the natural terrain features at a reduced scale by optically projecting overlapping aerial photographs oriented to each other and to pertinent data. Each of the diapositives is positioned on the focal plane stage of a projector. Light passes through the diapositives, then through the optical system of the projector to project the image of the terrain in a manner which is geometrically similar to the original photographic process, but optically reversed.

c. A true reduced scale reproduction of the terrain and of the angular and space relationships between the terrain and the camera stations is restored in miniature in the double projection. This is done by properly orienting the two projected images with respect to plotted points representing known positions on the ground.

d. This spatial model (fig. 1) is viewed stereoscopically, measurements are made within the model, and the detail shown in the model is then traced orthographically to a compilation manuscript.

8. Photography

a. Photographs used in multiplex mapping are normally exposed while the optical axis of the camera is vertical or nearly vertical. To maintain the vertical position, the camera is suspended in a mount over an opening in the bottom of the airplane fuselage. The mount provides a system for leveling the camera to hold its optical axis vertical, and for rotating the camera about its axis to keep the axis of the focal plane parallel to the direction of flight.

b. To compile a topographic map with multiplex equipment, it is essential that the most complete stereoscopic coverage possible of the area be made by aerial photography. Suitable photography usually results when adjoining photographs have an average overlap of 60 percent along the line of flight, and an average sidelap of 20 percent between adjoining flight lines. The percentage of sidelap specified depends on the terrain, the accuracy of flight maps, and the experience of the photographic crew. Crab and tilt can be tolerated to the extent that the photography will give complete stereoscopic coverage. Excessive crab and tilt make orientation of the multiplex models more difficult. The flight altitude should be as constant as is consistent with good photographic conditions. However, large variations in altitude may sometimes be compensated for with the multiplex equipment.

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CHAPTER 2

MULTIPLEX EQUIPMENT

9. Photographic Equipment

The camera used in producing photography for multiplex mapping must be manufactured and calibrated to a degree of precision at least equal to the degree of accuracy for which the multiplex is designed.

10. Site for Use of Multiplex Equipment

a. Since the use of multiplex in mapping consists of precise measurements made with delicate instruments, it is important to select a location where operators and equipment can function with a minimum of interference. The primary requirement for the location is freedom from vibration. A ground floor location having a solid foundation and concrete floors makes an excellent site.

b. A room approximately 10 by 12 feet, with proper facilities for ventilation, should be provided for each multiplex unit. Air conditioning to control dimensional changes in the map compilation medium is desirable (app. V).

c. Electrical outlets are necessary for the voltage regulator, the cooling unit, a table lamp, an overhead light, a ventilating fan (if necessary), and a circulating fan. Switches should be located conveniently for use by the operator.

d. The layout for a multiplex mapping organization varies with the facilities available. It includes a sufficient number of multiplex rooms to utilize the equipment, one or more darkrooms, one or more drafting rooms, a stock room, a repair room, filing space, and offices as required. Sufficient darkroom space, equipped with hot and cold water and sewer connections, should be provided for the making of diapositives and contact prints. The drafting room or rooms should be sufficient size to provide for drafting, editing, plotting, and layout work.

11. Components of Multiplex Equipment

a. This manual describes in detail only those items which are integral components of the multiplex system. Supplementary equipment common to conventional drafting, photographic, or computing procedures is omitted.

b. Topographic units equipped with multiplex are issued six different sets of equipment, as listed in DA supply manuals SM 5–4–6675–S19 through S24. The sets are designed to perform the following operations: S19, control; S20, drafting; S21, photographic laboratory; S22, plotting; S23, repair; and S24, supplementary (replacement) equipment.

c. Set 22 is a complete multiplex unit for compiling detail on the map manuscript and includes the following items of equipment:

(1) 2 adapters.
(2) 1 cooling unit.
(3) 1 fan, circulating, desk.
(4) 1 frame.
(5) 1 voltage control unit.
(6) 1 platen.
(7) 1 set of projectors (3 to a set).
(8) 2 spectacles (1 temple frame and 1 clip-on frame).
(9) 1 stereoscope.
(10) 1 table.
(11) 1 tracing table.

d. Set 19 is a multiplex unit for extending control. It is similar to set 22, but has 8 adapters and 2 each of the cooling units, nadirscopes, stereoscopes, tables, tracing tables, and a double frame. In addition, set 19 contains a fan, height gage, indicator dial, spectacles, and 4 sets of projectors (3 per set).

e. Set 21 contains the reduction printer, rectifier, and all photographic equipment required for preparing diapositives and contact prints from aerial negatives. Set 20 consists of drafting tools and supplies for use of the multiplex operator in preparing the map manuscript. Sets 23 and 24 are concerned with maintenance, repair, and replacement parts.

12. Reduction Printer

The reduction printer is essentially a reducing camera of high precision used to prepare the diapositives (positive transparencies of the aerial photographs on glass plates) required by the multiplex projectors. The following functions are particularly important in enabling the multiplex projectors to achieve the geometrically parallel reproduction of nature which is an essential principle of the multiplex.

a. Reduction of Negative Size. The reduction printer reduces an aerial photograph approximately according to the ratio:

$$\frac{\text{Focal length of camera}}{\text{Principal distance of projectors}}$$

More precisely, the reduction setting of the printer is based on the principal distance of the aerial negative, rather than on the focal length of the camera. Thus the effect of film shrinkage is taken into account. Since the cone of rays emanating from a projector must be geometrically similar to the original cone that entered the camera at the instant of exposure, the principal distance of the diapositive must be equal to the principal distance of the projectors. To accomplish this, provision is made for setting the reduction ratio precisely. If the reduction ratio were not accurately set, the projected cone of rays would be either slightly elongated or slightly flattened, with the result that the horizontal scale of the model would be slightly in error with respect to the vertical scale. With the proper reduction ratio, the vertical and horizontal scales will be equal.

b. Distortion Compensation. Two models of the multiplex reduction printer are now available. The earlier model was designed to introduce a distortion calculated to reduce the nominal lens distortion inherent in a 6-inch metrogon lens to as near zero distortion as possible. The newer model is equipped with interchangeable upper pressure plates; one of these is installed for use with distortion-free photography while the other plate (together with a spacer ring) is used with metrogon photography (fig. 3). Figure 4 illustrates the functions of distortion compensation and reduction of negative size in recovering the same angle between two projected rays as existed between the corresponding rays in nature; while figure 5 shows graphically the distortion correction of the printer for use with negatives taken with the metrogon lens.

c. Addition of the Principal Mark. The reduction printer is the source of the small cross printed on the diapositive, marking the principal point of the photograph. The original of this mark is etched on a glass plate in the negative plane of the printer. It is

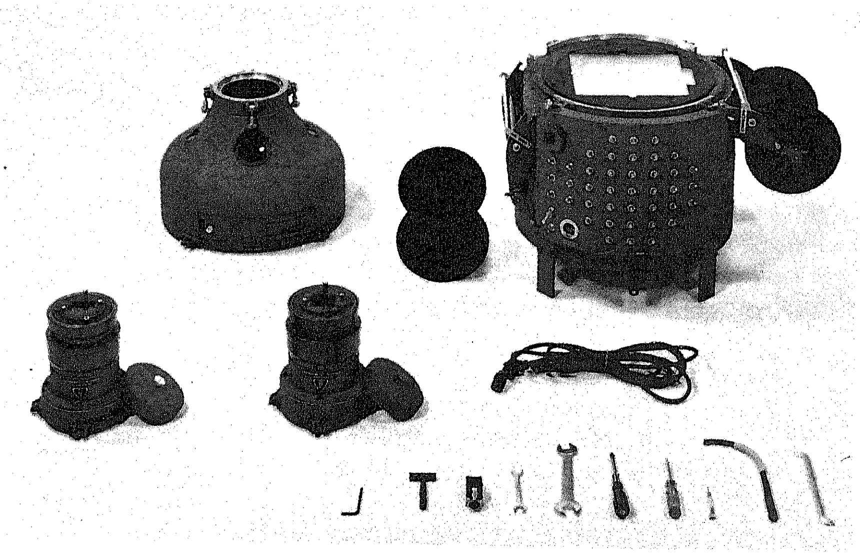


Figure 3. Reduction printer.

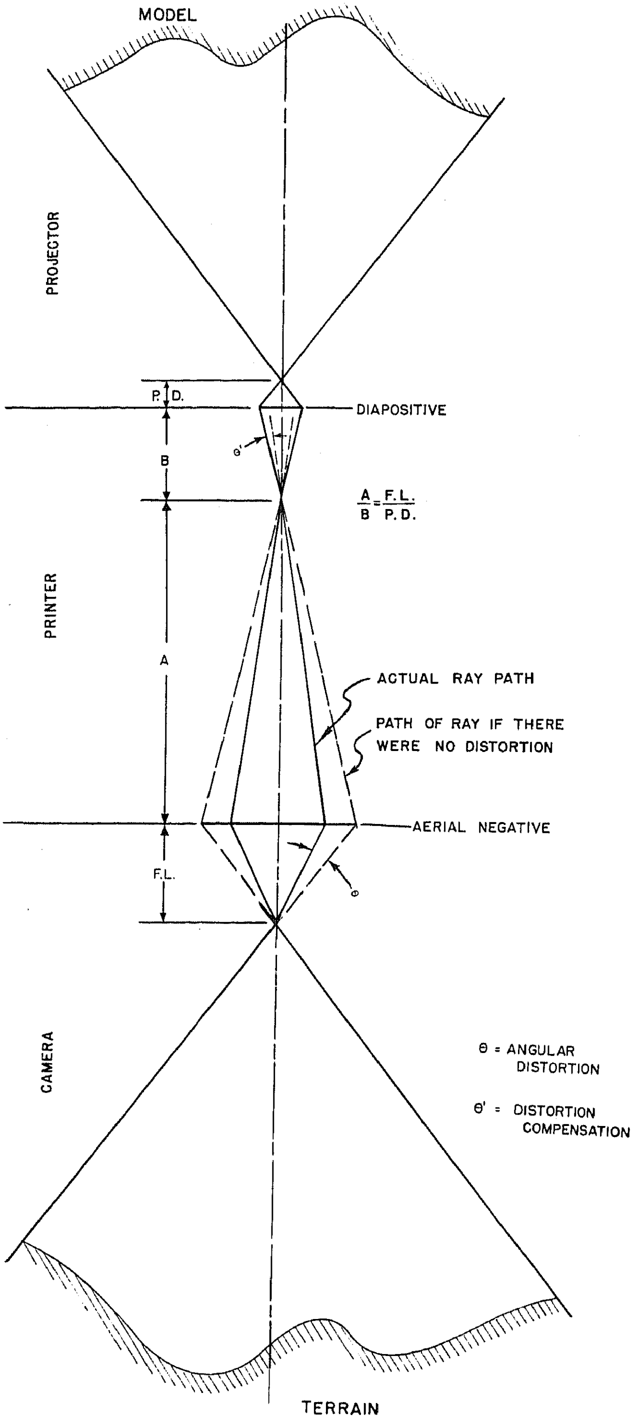


Figure 4. Schematic diagram showing ideal camera-printer-projector relationship, distortion compensation, and reduction of negative size.

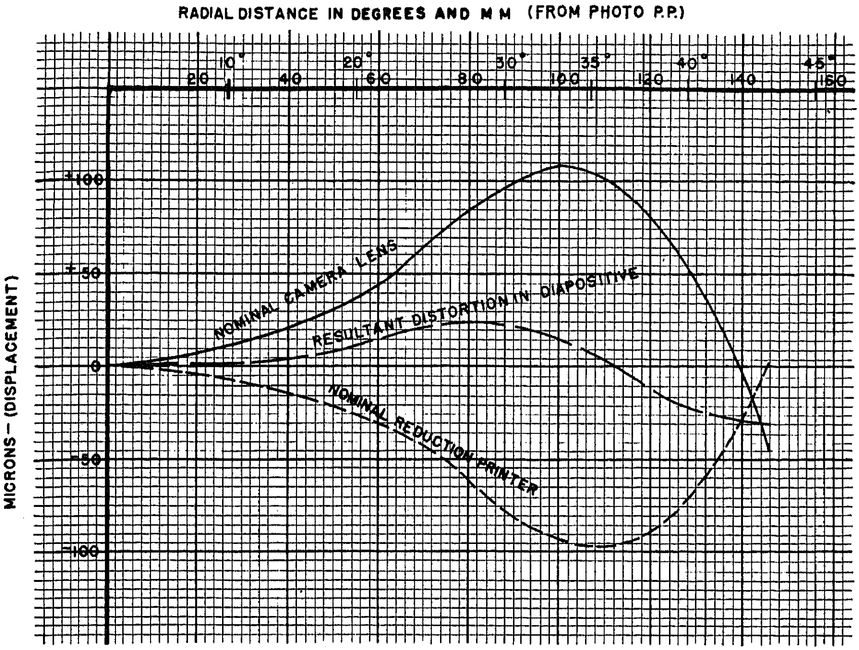


Figure 5. Radial distortion curves—camera and printer.

the responsibility of the printer operator to position the negative before a diapositive is exposed, by alining the fiducial marks on the negative with certain collimating lines on the plate glass.

13. Projector

An understanding of the multiplex projector optical system will be aided by reference to figure 6, which shows diagrammatically the path of a ray of light through the optical system. The essential parts of the multiplex projector shown in figure 6 are: the light source, the color filter, the condenser lenses in the condenser housing, and the camera body containing the projection lens and the diapositive stage. Since 1947, the Corps of Engineers has procured multiplex projectors without a stage plate. The camera body is sometimes called the "projector cone" or "lens cone." In a discussion of multiplex operation, it is convenient to distinguish between the two main assemblies: the *condenser housing* and the *base or body.* The components of this base portion of the projector will be described first.

a. Projection Lens. The multiplex projection lens is small and essentially distortion-free. Its focal length and aperture opening have been selected so as to bring the image of the diapositive to

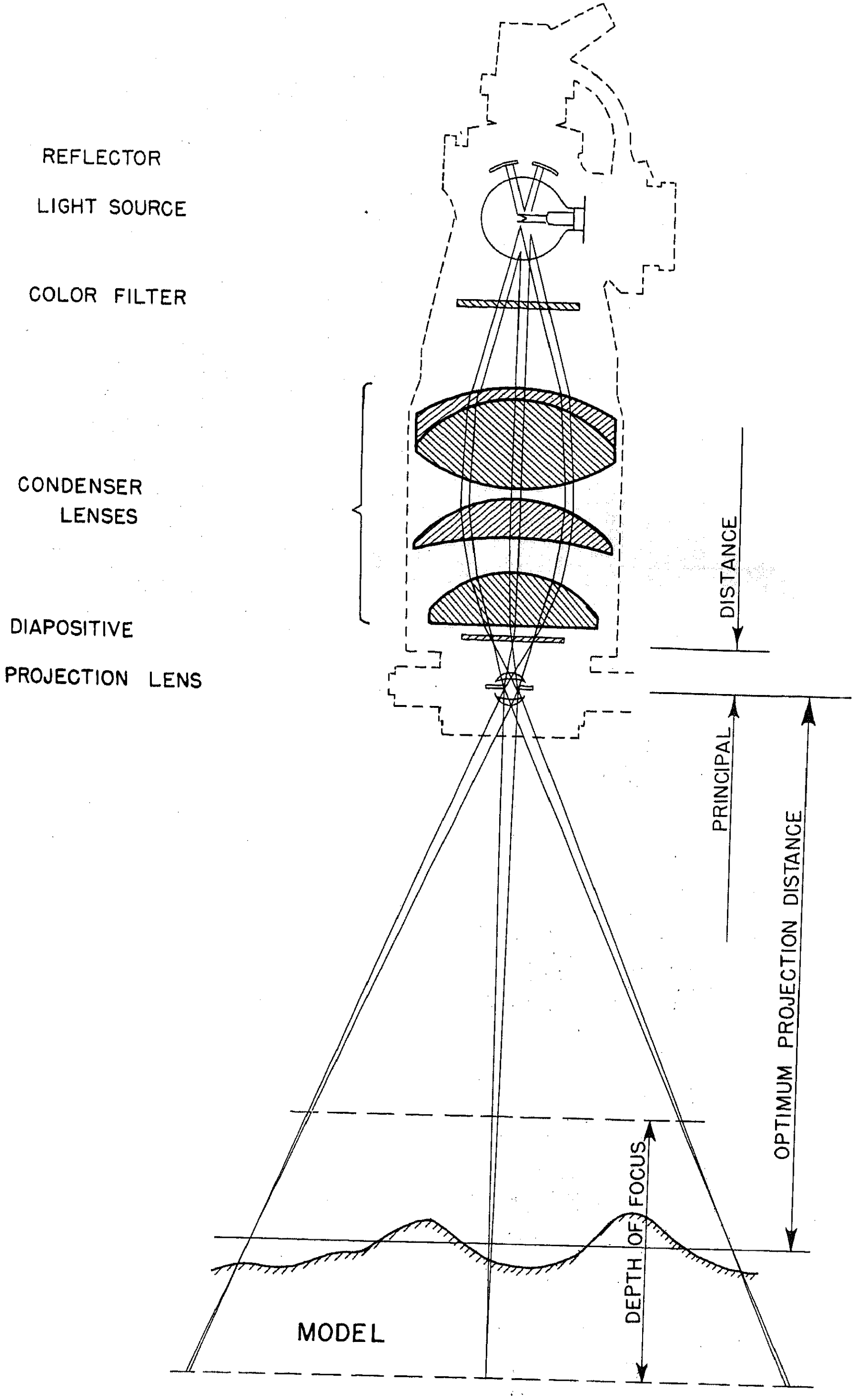
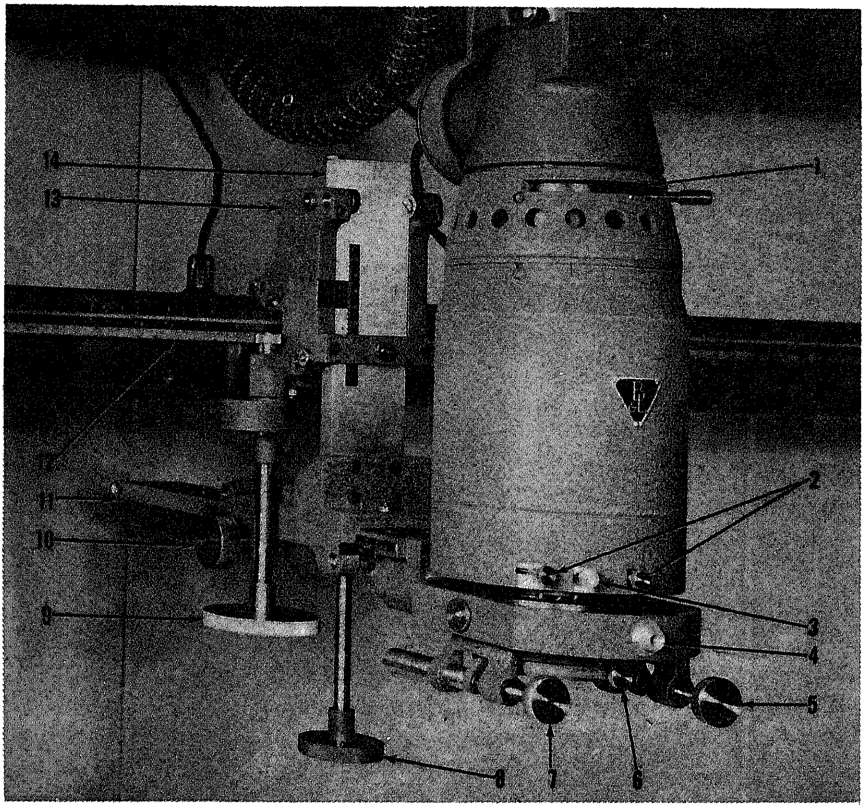


Figure 6. Multiplex projector optical system.

optimum focus in a plane 360 millimeters below the projector, with an approximate range from 270 to 450 millimeters within which the loss of definition is hardly perceptible. This depth of focus is necessary because the tracing table platen on which the projected image is viewed must be raised and lowered within the limits of the variations in relief in the stereoscopic model.

b. Diapositive Stage and Centering Mechanism. The diapositive is supported in the projector at a fixed distance above the projector lens. In the projector without the glass stage plate (fig. 7), the diapositive is supported upon four bosses, one under each corner, which duplicate those used to support the diapositive in the reduction printer. In the later model, these bosses are mounted in a frame which surrounds the diapositive and in which the dia-



1. Color filter
2. Centering adjustment screws
3. Centering arm
4. Boss
5. Tangent screw x-tilt
6. Swing clamp screw
7. Swing tangent screw
8. Knob z-direction
9. Knob x-direction
10. Knob y-direction
11. Horizontal arm or y-slide
12. Multiplex bar
13. Projector supporting bracket
14. Vertical arm or z-slide

Figure 7. Projector (assembled).

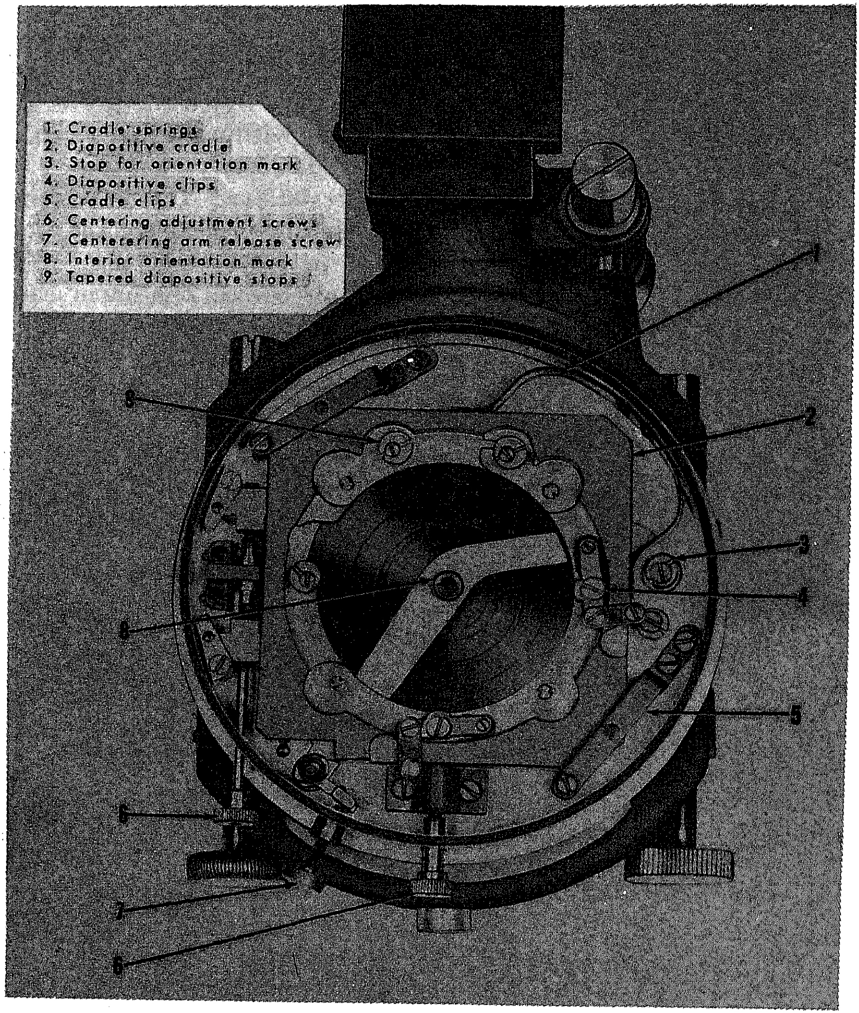

1. Cradle springs
2. Diapositive cradle
3. Stop for orientation mark
4. Diapositive clips
5. Cradle clips
6. Centering adjustment screws
7. Centering arm release screw
8. Interior orientation mark
9. Tapered diapositive stops
1
8
2
3
6
4
5
6
7
6

Figure 8. Diapositive stage.

positive can be securely fastened. Centering adjustment screws (2, fig. 7) slide this frame in its own plane, perpendicular to the lens axis, so that the principal point of the diapositive can be alined with the principal point of the projector.

c. *Principal Point Indicating Device.* One of the great differences to be found among recent designs of the multiplex projector is in the device employed to indicate the principal point. Two different indicating devices are briefly described below.

(1) *Centering arm.* The centering arm device may be seen in figure 8. The principal point (interior orientation mark, 8, fig. 8) of this projector is indicated by a small dot

etched on a glass reticle mounted on a movable arm. Normally out of the field of view, this arm is pivoted at the end so that it may be swung out beneath the diapositive by an external release screw (7, fig. 8). Releasing the arm against the stop automatically places the dot at the principal point of the projector.

(2) *Stage plate.* In the stage plate type of projector, the diapositive is supported, not upon bosses, but upon a glass plate called a stage plate. Spring clamps force the diapositive down against this plate; the centering mechanism moves only the diapositive itself. A disadvantage of this arrangement is that in time the stage glass may become scratched from the diapositive sliding upon it. The advantage of the stage plate is that the marking of the principal point, or dot, is on the upper side of the stage glass.

d. Projector Supporting Bracket. In addition to supporting the projector on the multiplex frame, the bracket provides the body with six freedoms of motion—three of translation and three of rotation—which are essential to the complete recovery of the photograph orientation. The supporting bracket provides translational motions through an L-shaped arrangement of two sliding members: a horizontal arm, or y slide (11, fig. 7), and a vertical arm, or z slide (14, fig. 7). The whole assembly is designed to be hung on the x slide of the multiplex bar along which it can be moved in the x direction. Although the orientation of these three slides with reference to some fixed part of the multiplex supporting table changes slightly with tilt of the supporting frame, the orientation of the slides serves to designate the x, y, and z directions sufficiently well for descriptive purposes. In certain instances, it may be convenient to assume an explicit orientation of one or more axes with reference to the supporting table, or to the model air base, or to some other designated element. The knobs that control the translational motions are grouped at the rear of the projector: knob (9, fig. 7) drives the projector in x; knob (10, fig. 7) drives it in y; and knob (8, fig. 7) drives it in z. The projector is mounted in a gimbal affixed to the front of the y slide. This mount permits the camera body to be rotated about three axes that normally are perpendicular to one another. Rotation of the camera body within the inner ring of the gimbal is about a z axis and is called swing. Rotation of the inner ring is about an x axis, secondary axis, and is called x tilt. Rotation of the outer ring is about a y axis, primary axis, and is called y tilt. The x tilt and y tilt are controlled by tangent screws (fig. 7), which permit the camera body to be tilted from its normal position approximately 10° crosswise to the line of flight direction. A third tangent screw (7, fig. 7) is used for the finer adjustment of swing. For the larger adjustments, the swing clamp screw (6, fig. 7) is loosened, permitting the camera body to be rotated manually through a full circle.

e. Lamp Houses. The earlier multiplex lamp house design places the bulb socket at the very top, in which a T–8 bulb is mounted base up. The condensing system does not include the reflector. In the newer style projector, a prefocused G–16½ bulb is mounted horizontally. This change not only permits a reflector to be used for added concentration of light, but also provides better ventilation for the bulb. A fitting to which an air hose can be attached is provided on both types of lamp housing, although forced air cooling is not required by the newer type lamp house. Adjustments are provided on the bulb mount for focusing the maximum light upon the aperture of the projection lens. The small size of the aperture opening limits the size of the filament of the bulb, and indirectly limits the filament voltage rating. 20-volt bulbs are now commonly used. The color filter (1, fig. 7) is inserted in a slot below the bulb and above the condenser lenses. Filters of red glass are interchangeable with filters of blue glass, so that complementary colors for the projection of the stereoscopic pair of photographs can always be provided.

14. Tracing Table

a. Function. The multiplex tracing table shown in figure 9 provides the means of relating the stereoscopic model and the manuscript. It forms the connecting link between these two. Essentially, the tracing table provides a screen on which the projected model can be viewed; a floating mark (2, fig. 9); a height indicating counter (15, fig. 9); a plotting pencil (9, fig. 9); and a horseshoe base (6, fig. 9).

b. Screen and Floating Mark. The platen, or viewing screen, is a circular plate about 3½ inches in diameter. The floating mark is a single luminous dot, formed by light from a small bulb beneath the platen shining through a hole in the platen, approximately 0.004 inch in diameter. Recently, an improved floating mark has been developed by mounting a small sapphire in this hole to disperse the light through a wider angle. The intensity of the luminous mark can be varied by a rheostat (5, fig. 9) mounted on the base.

c. Height-Indicating Scale. The height of the floating mark can be varied by turning the elevating wheel (13, fig. 9) which drives the platen mount. The vertical movement of the platen may then be shown by one of several types of height-indicating mechanisms now in use. One device is the vernier type, with a scale

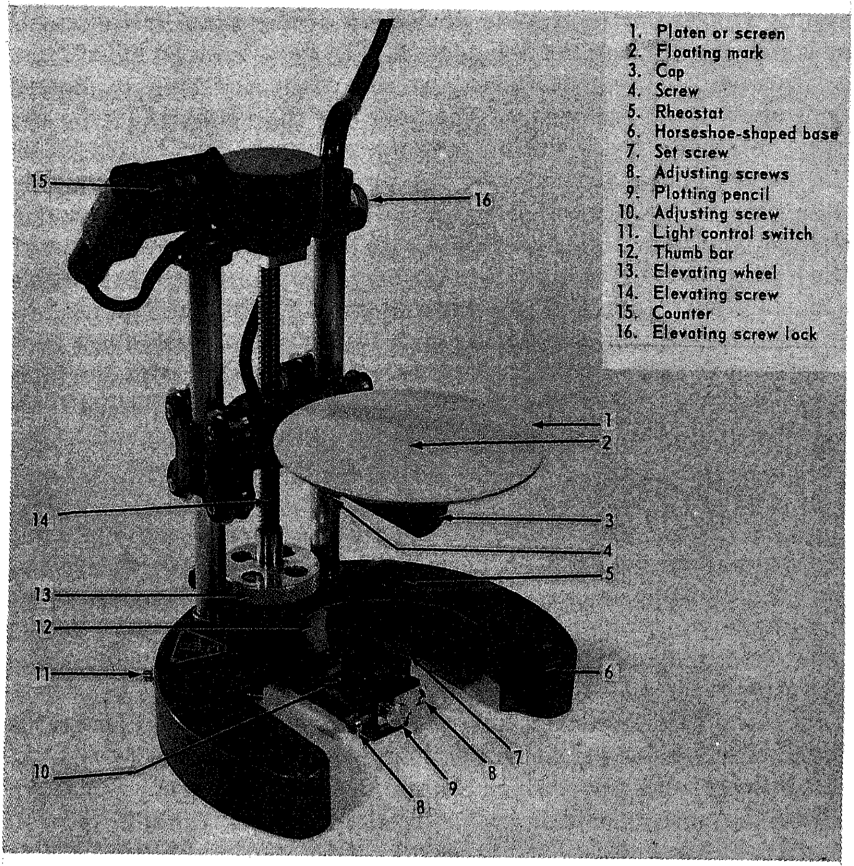


Figure 9. The multiplex tracing table.

engraved directly on the left column of the tracing table to indicate the millimeter travel and afford a minimum reading of 0.1 millimeter. In the second type, the vernier and scale have been replaced by a counter geared directly to the elevation screw which also indicates the millimeter travel of the platen. The third type of indicator also employs the counters, but is equipped with interchangeable gears to change the ratio between elevation screw and counter to afford direct foot or meter readings at commonly used compilation scales. When changing from fixed ratio counters to vernier type, the conversion from millimeter readings to either meters or feet is readily made from tables, prepared in advance, that list for each foot or meter the equivalent millimeter value at each of the commonly used scales.

d. Plotting Pencil and Base. The plotting pencil is supported directly below the floating mark so that it will mark upon the manuscript the orthographic projection of any point in the model at which the floating mark is placed. The pencil can be lifted from or lowered to the manuscript by means of the ring or button (not shown) at the rear of the base. A thumb bar (12, fig. 9) helps to steady the lowering motion. A weight can be placed on the pencil chuck to increase the pressure. A 6–8-volt bulb in each side of the base lights a small area of manuscript around the plotting pencil. A switch (11, fig. 9) controls these lights and the light provided to illuminate the height scale. These three lights are usually wired in series to operate from the 20-volt supply. The tracing table slides easily over the manuscript on small agate feet. Provision is made for adjusting these feet, together with the plotting pencil, to insure that the pencil is perpendicular to the table and centered below the floating mark at all times.

15. Supporting Frame

a. Function. The multiplex supporting frame consists of a horizontal bar and one or more uprights that support this bar over the multiplex table. In addition to supporting the projectors, one of the functions of the frame is to tilt all the projectors as a unit, thereby providing a simple means of leveling either a model or a strip.

b. Bar. The multiplex bar is 7 feet long and spans the table lengthwise. Attached to and extending the full length of the bar is a smooth track upon which the projectors can be hung and along which they can be slid in an x direction. A rack running the full length of this x slide engages a pinion gear on each projector to provide a means of driving the projectors along the slide. Some 7-foot bars are so made that two may be joined together to form a longer bar. Such a frame is more easily transported than one with a single 14-foot section. It has an operational disadvantage in that the center support makes leveling by means of the frame more difficult.

c. Uprights. The space beneath the projectors must be unobstructed; therefore, the multiplex bar is supported by uprights at each end, or in cantilever fashion by one or more uprights at the back of the table. The inverted T-frame supports each end of the bar on a vertical, threaded post. This bar can be inclined lengthwise by handwheels which regulate the height of each end independently. The base of each upright is supported on foot screws by which the entire frame can be tilted in any direction. One of the posts is usually pivoted at its junction with the base; otherwise, the four-point support frame would make it possible to put an undesirable twisting stress on the bar. The handwheels, foot screws, and pivot can be securely locked when orientation of the model is completed.

16. Supporting Table

a. Table Top. Multiplex table tops are uniformly about 3 feet wide, measuring from front to back, and 7 feet in length. Longer supporting frames can be placed on two tables that have been placed end to end and carefully alined. The primary requirement of the table top is that its upper surface must be flat within a few thousandths of an inch, because this surface is the datum plane of the instrument. Aluminum table tops are reinforced by heavy ribs cast into the underside. The legs can be fastened directly to the top casting. Each leg must be carefully adjusted after the table is set up, to eliminate any warp or bending of the top surface.

b. Table Frame. The metal top must be supported on a frame, preferably one of steel, as the weight of the table plus the weight of the multiplex bar and projectors is considerable. The multiplex table frame is provided with adjustable feet, so that all the legs can be brought to bear equally upon the floor. If desired, the plane of the table top can be established as a truly horizontal plane by means of these foot adjustments. It is not necessary to have the table top exactly leveled except in unusual instances when some gravity-dependent device such as a plumb bob or a spirit level is to be used in connection with the orientation of the projectors and model.

17. Filter Spectacles

The filter spectacles which the observer must wear to see the stereoscopic model have one red lens and one blue lens. The red lens is always plane; the blue lens is now made with a slight negative correction to balance the refraction of the two colors. For the observer's convenience in viewing consecutive models without having to exchange the projector filters, the spectacles are reversible.

18. Electrical System

a. Components. The multiplex electrical system usually consists of a transformer, a voltage regulator containing two or more selector switches and two or more rheostats, a multiple outlet strip along the top or back of the horizontal bar, and the interconnecting wiring. The function of the transformer is to reduce the line voltage to the maximum required by the various light bulbs. The selector switches are wired to the multiplex outlets, except one or two constant voltage outlets reserved for the tracing table connection, so that any desired pair of projectors can be lighted.

b. Voltage Regulator. The projectors and tracing table are operated on 20 volts. In order to reduce the line voltage to this and also provide means for regulating the intensity of illumination of the various projectors, a voltage regulator is included as part of the equipment. Voltage regulation of individual projectors makes possible equalization of illumination of the two projectors in any portion of the model being worked, thus improving the stereoscopic impression of the terrain. It is desirable to use the maximum illumination available, but portions of a model may require a decrease of the illumination of one projector to obtain equal lighting. The dial type regulator has a box 14 by 23 by 20 cm, which contains the transformer, and a box 21 by 28 by 11 cm, which contains the regulator unit. Three cable connections are provided: one on the primary side of the transformer for connection to the source of the power; a second for connecting the transformer and the regulator; and a third for connecting the regulator to the frame by means of the 13-conductor plug. The switch located on the transformer unit disconnects the transformer from the line. The regulator unit is provided with four circuits, A, B, C, and D, each of which can be used to supply current to any of the ten numbered outlets of the frame by setting the selector corresponding to the outlet which it is desired to light. Each circuit is controlled by a toggle switch. A rheostat is provided on each circuit to control the intensity of illumination. By means of the voltmeter selector switch, the voltage of any of the four circuits may be read on the voltmeter. The maximum voltage which can be supplied at the outlets on the frame is approximately 21.5 volts with four lamps on. The rheostat will reduce this voltage to 8 volts. When the rheostat is set at the index mark, the normal voltage for the lamps, 20 volts, is being supplied. At 21.5 volts, the intensity of illumination is increased, but the life of the lamp is decreased. An additional circuit which serves those outlets on the frame marked O (or T and L) supplies 21.5 volts at all times. Each of the five circuits is fused with a 10-ampere fuse located on the fuse block. The line is fused by a 6-ampere fuse. A shielded lamp, controlled by a switch, serves to illuminate the regulator unit. Since the dial type regulator is very light and easily moved, it is normally set on the multiplex table.

19. Cooling System

Forced air cooling for the multiplex projector without glass stage plate is optional. The older type multiplex projector with glass stage plate requires cooling to dissipate the heat generated by the projection light. A fitting for an air hose is provided on both types of lamp house and the supporting frame carries a header to which several hoses can be connected. A large hose connects the header either to an individual fan or in plants having several multiplex units, to an air duct connecting all the units to a central fan. The cooling system can be either a blower or a suction type system. An advantage of a system that blows air into the projector is that a filter can be used on the air intake to catch the dust that otherwise would be sucked into the lamp house, where it would accumulate on the filter and upper condenser lens, and rapidly decrease the efficiency of the lighting system. In order to dissipate the heat produced by the 100-watt projector bulbs, a cooling unit is supplied with each frame. Two types are used, one producing the cooling effect by suction, and the second by blowing; the latter is supplied on latest procurement.

a. Suction Type. The suction type cooling unit is equipped with a 76-mm olive-drab sleeve on the suction side for connection with the 76-mm hose, which is supplied as part of the frame. The discharge pipe is threaded on the inside for a 64-mm pipe connection. The blower is directly connected to a ¾-hp, 1-phase, 60-cycle, 110/220-volt motor which operates at 3,450 rpm. The motor should be operated on 220 volts if possible. In order to lessen the noise and decrease vibration, the possibilities of locating the suction type cooling unit, either on the ground outside the building or on the roof, should be considered in selecting the site for the multiplex rooms. To house the units, there should be provided a waterproof shelter so constructed that the motor is ventilated and easily accessible for servicing. Piping connections from the multiplex rooms to the blower can be galvanized iron or ordinary black pipe, and should be kept as short and straight as possible. Care should be taken that all joints and seams are airtight. If it is found impracticable to install the cooling units outside the multiplex rooms, the noise and vibration can be reduced by exhausting the air through a muffler. A satisfactory muffler can be constructed by putting a series of baffles in a box constructed of celotex or a similar material. Vibration can be reduced by mounting the blower on sponge rubber. The 76-mm (diameter) hose should be placed so that it does not touch the multiplex table or frame, as vibration in the hose would be transmitted to the projectors and cause parallax in the multiplex models.

b. Blower Type. The blower type of cooling unit produces its cooling effect by forcing air through the cooling header of the frame and the projectors. It is operated while mounted in its case. A zigzag filtering units fits over the top opening. The incoming air passes through the filter into the suction intake of the blower. The discharge pipe is fitted in the side of the case for connection with the 3-inch olive-drab hose for joining the cooling header of the frame. The opening may be covered by a plate when the unit is not in use. The blower is directly connected to a 1/3-hp, 1-phase, 60-cycle, 110/220-volt motor which operates at 3,450 rpm. The plug for the electrical connection and an OFF-and-ON switch are located in the recess. The wooden top is fastened to the case by four clamps. Inside the top are two flat compartments for holding two spare filtering units and 6 meters of electrical cable for connection from the unit to the power outlet. A few blowers in service are not equipped with the filtering unit. Rock wool is used as insulation between the wooden case and the galvanized-iron liner. The blowers are removed from their cases during operation. The installation of the blower cooling unit presents no problem, since the noise of the blower is not objectionable. This blower can be placed in any convenient location where it can be connected to the cooling header of the frame. The 3/4-hp motor is equipped with ball bearings packed with grease. The old grease should be cleaned out once a year and the bearings repacked. The 1/3-hp motor has wool-packed bearings which should be oiled every two weeks.

20. Care of Equipment

Tools are provided for setting up the instruments for operation, and for making minor adjustments. Adjustments and repair of the instruments should not be attempted by anyone who is not thoroughly familiar with construction and operation features. Too much emphasis cannot be placed on the importance of care in handling instruments. It is the duty of each operator to keep his equipment clean and properly lubricated. The threads of tangent screws, the projector slides, and the vertical columns of the tracing table are particularly likely to collect dust and grit and should be frequently cleaned and lubricated. Glass surfaces should never be rubbed with a rough cloth or touched with the fingers, as the glass may be permanently scratched. Special cleansing tissue or a soft lintless cloth should be used to clean the glass surfaces after they have been dusted with a clean camel's-hair brush. Special care must be taken in this respect when placing diapositives on the stage glass. Thoroughly dust the stage glass and the diapositive immediately before placing the diapositive in position.

CHAPTER 3

CALIBRATION AND ADJUSTMENT OF MULTIPLEX EQUIPMENT

21. Introduction

The procedures involved in calibrating and adjusting multiplex equipment are normally of two classes: routine procedures, or those which are the responsibility of the multiplex operator; and laboratory procedures, or those requiring the use of special tools and equipment in the hands of skilled technicians. Routine procedures will be described in this chapter. A detailed discussion of laboratory procedures is beyond the scope of this manual; however, those methods that the multiplex operator can use for roughly checking laboratory calibrations are listed in paragraph 24.

22. Setting Up

After the multiplex table is set up, the first step is to level the table. The table top is the reference plane and could be used in a tilted position, but the level position is usually more convenient in setting up the remainder of the apparatus. The frame is set up on the table, on the far side from the operator, and the cross bar is leveled. Projectors are hung on the frame by means of projector brackets. A turn of the x motion insures proper meshing of the pinion on the rack. The z slide is set at approximately the center of its range of travel and the height of the projectors is adjusted by raising or lowering the bar until the projector lenses are all approximately 360-mm above the surface of the tracing table in the middle of its range. Each projector is then approximately leveled with a spirit level if available, otherwise by sight. The best starting position for all projectors is that obtained when it is assumed that the flight altitude was constant and the camera was vertical.

23. Lighting

a. Lampheads, lamps, and condensers are assembled. With the camel's-hair brush, dust is removed from all glass surfaces within reach. The condenser is carefully slipped over the top of the projector body, the cooling attachment connection is made, and the light cable plugged into a proper socket on the frame.

b. Each projector is then adjusted for even illumination, to remove spectral color, by centering the lamp filament with respect to the condenser and the lens opening (pars. 28 and 29). The illumination is correct when the field is clear, or when only a slight, evenly distributed color remains in the corners.

24. Adjusting the Setup

Adjustments that primarily affect the convenience with which visual observations can be made are listed below. Anything hindering the operator's observations may result in errors in the map compilation as serious as errors due to faulty calibration of the equipment. When a complete adjustment and check of equipment is made, it is important that the order in which these operations are listed be followed closely. Items *g* and *h* below are highly critical to the accuracy of the compilation.

a. Adjust the floating mark bulb.

b. Check the verticality of the tracing table columns.

c. Center the plotting pencil.

d. Orient the axis of the filament coil (in the newer type lamp house only).

e. Position the projector bulb.

f. Check the adjustment of the reflector (in the newer type lamp house only).

g. Check the principal distance of the projector.

h. Check position of the principal point of the projector.

25. Adjusting the Floating Mark Bulb

The position of the bulb beneath the hole in the platen of the tracing table affects the visibility of the floating mark, especially at the far edge of the model. Whenever this bulb is replaced, it should be repositioned as follows:

a. Loosen the screw (4, fig. 9) on the underside of the platen carriage.

b. Move the bulb back and forth by sliding the screw in its slot, at the same time viewing the floating mark at a low angle.

c. When the position of the bulb affording the brightest light is found, lock the bulb in position by tightening the screw.

26. Checking Verticality of Tracing Table Columns

To insure that the vertical movement of the floating mark is perpendicular to the supporting table top, the three agate feet of the tracing table are so mounted that each can be adjusted up or down independently until the columns on which the platen carriage rides are perpendicular to the plane of the feet. This is a laboratory adjustment which the operator can check as follows:

a. Lower the platen as far as it will go. Illuminating one projector, place the floating mark on any well-defined image point and plot this position with tracing table pencil, first making sure that the pencil is sharpened to a carefully centered point.

b. Without disturbing the elevation of the platen, turn the tracing table 180° and replot the same image point. If there is a discrepancy between the two plotted positions, tentatively adjust the pencil point to a midpoint, as described in paragraph 27.

c. Raise the platen to its highest point. Repeat the above procedure of plotting and checking a point, which may be the same or some other well-defined image point. If a discrepancy is now apparent at this elevation, it indicates that the columns are not plumb and the table requires laboratory adjustment. This adjustment needs to be checked only occasionally.

27. Centering the Plotting Pencil

Centering the plotting pencil is normally the only routine adjustment made by the operator. The pencil lead should at all times be sharpened to a carefully centered point. The purpose of the adjustment is to center the pencil directly beneath the floating mark. This adjustment presupposes that the columns of the tracing table are perpendicular to the plane of the feet of the tracing table. The adjustment is made as follows:

a. Lock the platen at a fixed height, preferably at about the average plane of a model. Illuminate one projector, place the floating mark on any well-defined image point, and plot this position with the tracing table pencil.

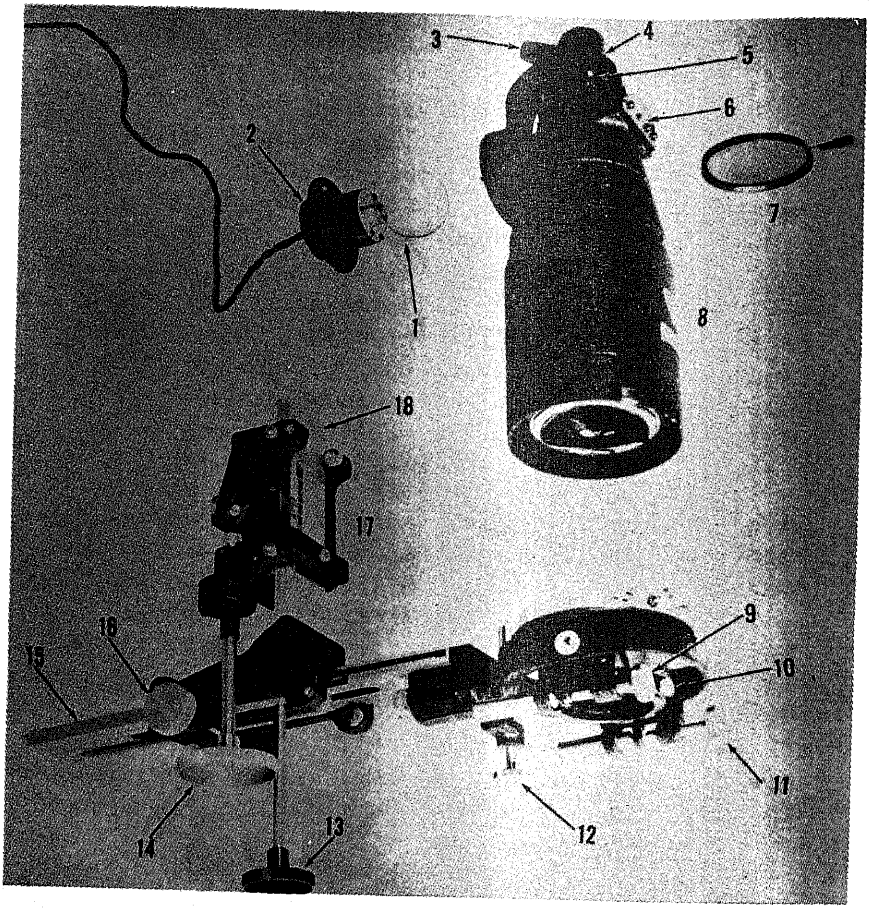
b. Turn the tracing table 180° and replot the same image point. If there is a discrepancy between the two plotted positions, mark a midpoint between the two.

c. Keep the floating mark on the same image point and loosen the two adjusting screws (8, fig. 9) at the sides of the pencil chuck. Shift the chuck by means of these two screws and the screw (10, fig. 9) behind the chuck until the pencil point moves to the midpoint position. Tighten the side screws to lock the chuck in position.

d. Check the adjustment by repeating the procedures in *a* and *b* above. The operator should check this adjustment as frequently as required to hold the pencil in the midpoint position.

28. Orienting Axis of Filament Coil of Projector Bulb

This adjustment applies only to lamp houses, such as the one shown in figure 10, in which the bulb (1) is mounted horizontally. With this orientation of the bulb, the axis of the filament revolves in a vertical plane when the socket mount is rotated. The best illumination is obtained when the filament coil axis is vertical, or



1. Bulb
2. Bulb-rotating ring
3. Air hose fitting
4. Vertical bulb adjusting ring
5. Lateral adjusting screws
6. Adjusting screws
7. Color filter
8. Condenser housing
9. Swing tangent screw
10. Swing clamp screw
11. Tangent screw, x-tilt
12. Tangent screw, y-tilt
13. Knob, z-direction
14. Knob, x-direction
15. Horizontal arm or y-slide
16. Knob, y-direction
17. Projector supporting bracket
18. Vertical arm or z-slide

Figure 10. Projector (disassembled).

parallel to the axis of the optical system. Whenever a bulb is replaced after this adjustment is once made, the filament coil axis will always come to a vertical position if the three-holed flange of the socket assembly is replaced with the same hole at the top. The operator needs to check this adjustment only when he suspects that it may have been disturbed. To adjust the axis of the filament coil:

a. Hold an auxiliary lens below the projector.

b. Move this lens up or down until it forms an image of the lighted filament upon the table top.

c. Rotate the bulb by the knurled ring (2, fig. 10) at the back of the bulb socket until the filament image appears

29. Positioning the Projector Bulb

Before this adjustment can be made, either a diapositive or a clear glass plate of equal thickness must be in place in the projector.

a. With the lamp house in place, turn on the lamp to maximum intensity. Remove the color filter. Hold a white screen (the back of a contact print will do) close beneath the projector lens so that the whole field of illumination can be viewed.

b. Using the two lateral adjusting screws (5, fig. 10) on the bulb mount, center the filament so that any color appearing in the illuminated area is symmetrically disposed. This color is caused by chromatic aberrations of the condensing system. If the filament is now viewed by holding a small auxiliary lens beneath the projector, it should appear well centered in the aperture opening, which appears as a faint circle surrounding the filament image.

c. Using the knurled ring (4, fig. 10) at the top of the lamp house, adjust the bulb vertically until the illuminated field is as color free as possible. In particular, any bluish cast should be avoided, a tinge of yellow is not undesirable, and a residual ring of light yellow around the outer edge of the field may often have to be accepted.

30. Checking Adjustment of the Reflector

The reflector in the newer-style lamp house (fig. 10) is properly adjusted at the factory and should seldom need readjusting. Its adjustment is a laboratory procedure. The adjusting screws (6, fig. 10) should not be disturbed by the operator. The operator can check the adjustment of the reflector as follows:

a. Position the bulb carefully by the procedure given in paragraph 29.

b. Grasp the lamp house firmly with both hands and raise it from the projector base until the image of the filament is seen on the table.

c. Displace the lamp house horizontally to include the image formed by the reflector. Because of the hole in its center, the reflector images only the oblique rays. If the reflector is properly adjusted, the reflector image should be the same size as the direct and brighter one formed by the condenser lenses alone, and the two images should be superimposed. Adjustment of the reflector is needed if one image is readily distinguishable from the other.

d. As an improperly positioned bulb could also be the source of displacement between direct and reflected images of the filament, it is suggested that the bulb be repositioned by trial when a displacement is noted, until the two images are brought together.

With the lamp house then replaced on the base, if the illuminated field shows an undesirable amount of color, the lamp house should be sent to the equipment repairman for readjustment of the reflector.

31. Checking Principal Distance of the Projector

The two procedures for checking the principal distance given below will afford only a rough check, for the purpose of discovering a relatively large error, as they are capable of but one-fifth to one-tenth of the accuracy required in the laboratory calibration of the principal distance. The principal distance is accurately calibrated before the projector leaves the factory and seldom needs recalibration. The operator will, therefore, check the principal distance only when there are consistent indications that it may be in error. The indication of an error of the principal distance is basically an inequality between the horizontal and vertical scale of the model. If the operator should find it necessary to check a principal distance, he will need one accessory that is not required in the everyday operaton of the multiplex, a diapositive having calibrated graduations as indicated in figure 11. A glass plate etched with a precise grid is commonly used in the laboratory calibration of the principal distance, and carefully made photographic copies of such a grid can be used in the following procedures.

a. Suggested Procedure. The preferred procedure for checking principal distance is:

(1) Place the grid plate in the projector and center one of the grid intersections. Swing the camera body until the grid lines are roughly parallel to the x and y axes of the projector.

(2) Viewing the projected grid on the table top, tilt the projector (x and y tilt) until the pattern is precisely rectangular by measurements. Triangle *OAB* (fig. 11) is now similar to the triangle *Oab*. The grid plate is also parallel to the table top, provided the optical axis of [illegible] straight line.

(3) On the grid line passing through the principal point in the x direction, select two grid intersections, one on each side of the principal point and each approximately 20 millimeters from the principal point. Using a needle in place of the tracing table pencil, and having checked the calibration of the tracing table with the needle in place, plot the positions of the selected grid intersections, once with the platen at its lowest elevation and again with the platen at its maximum height. Calculate the sum of the two displacements, $d_1 + d_2$.

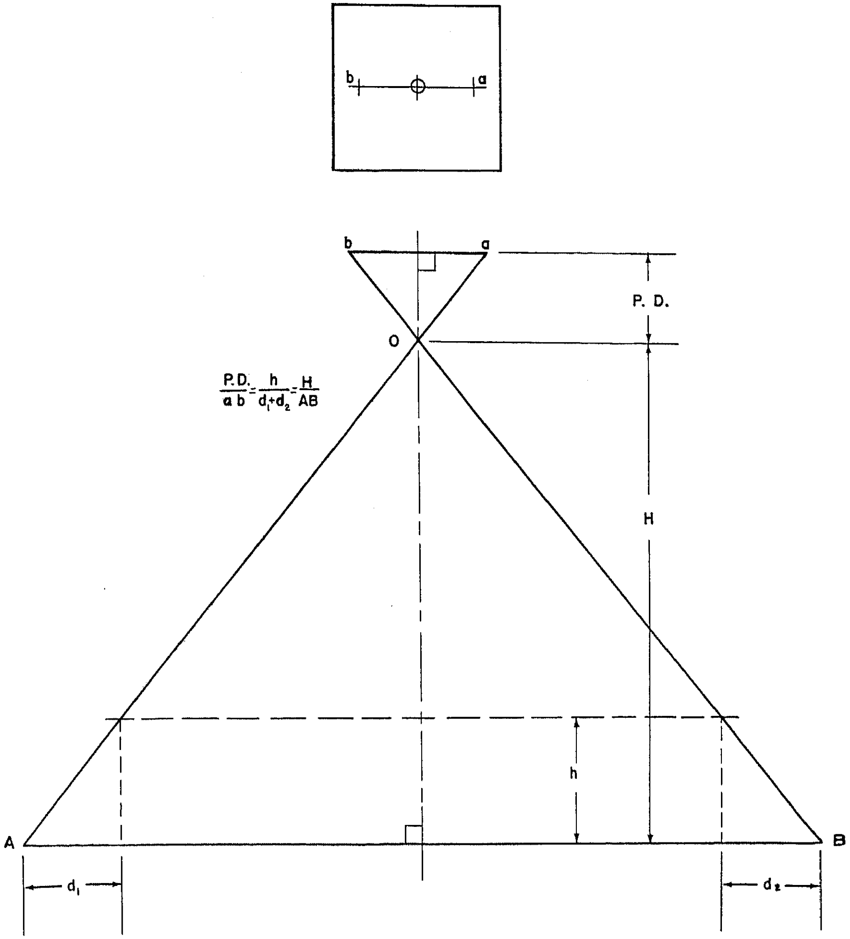


Figure 11. Checking principal distance by projected grid.

(4) Compute the principal distance (*P.D.*) according to the relationship $P.D. = \frac{h \times ab}{d_1 + d_2}$ where h is the vertical range of the platen and ab is the distance on the grid plate between the two grid intersections.

b. Alternate Procedure. On the front of the outer gimbal ring is a conical boss (4, fig. 7). The following procedure makes the assumption that the center of this boss is exactly at the height of the exterior perspective center when the y slide of the projector is supported in a level position. The assumption of this condition is warranted, for it is a condition which the manufacturer attempts to attain very closely. Subsequent adjustments of the principal distance will disturb this relationship slightly, as the principal distance is altered physically by a movement of the lens in relation to the rest of the camera body while the diapositive plane remains fixed.

(1) Tilt the supporting frame until the y slide of the projector is parallel to the top of the multiplex supporting table. The y slide may be leveled by means of a bubble, provided the table top has also been leveled.

(2) Place the gird plate in the projector and center one of the grid intersections by measurements.

(3) Viewing the projected grid on the table top, tilt the projector as described in *a* above until the pattern is precisely rectangular.

(4) Measure the distance AB (fig. 11) on the table between two grid intersections in line with the principal point and approximately 20 millimeters either side of the principal point. The distance ab between the same two points on the grid plate should also be measured if not known.

(5) Measure the height H of the center of the conical boss above the multiplex table.

(6) Compute the principal distance ($P.D.$) from the relationship $P.D. = \frac{H \times ab}{AB}$.

32. Checking Position of Principal Point of the Projector

The principal point is accurately calibrated before the projector leaves the factory and seldom needs recalibration. The operator will, therefore, check the principal point only when there are indications that its position may be in error. A position error of the principal point is often indicated by its effect on elevations in the model. Like a principal distance error, the effect of a given error of the principal point increases in proportion to the relief in the model.

a. Recommended Procedure. This procedure requires the use of the plate with the precise grid described in paragraph 31.

(1) Place the grid plate in the projector and carefully center one of the grid intersections.

(2) Viewing the projected grid on the table top, tilt the projector (x and y tilt) until the pattern is precisely rectangular by measurements.

(3) Using a tracing table that has been carefully calibrated with respect to the verticality of its columns, place the

floating mark on the principal point image. Without moving the base of the tracing table, move the platen up and down through its full range. If the floating mark and the principal point image do not remain coincident, that is, if the principal point ray is not plumb, the principal point is in error.

b. Alternate Procedure. This procedure does not require the use of a grid plate, but it does make the assumption that the optical axis of the projector lens is a straight line and that the diapositive plane is perpendicular to the mechanical axis of swing.

(1) Carefully center a diapositive in the projector.

(2) Observing the principal-point mark on either the multiplex table or platen, slowly rotate the projector by swing motion through 180°, being careful not to disturb any of the other motions. If the principal-point mark does not remain stationary, an error in the position of the principal point is indicated.

CHAPTER 4

PRELIMINARY OPERATIONS

33. Discussion

Extensive planning and evaluation of data are required to initiate most mapping projects. A very brief discussion and general outline of the preliminary planning, preparations, and operations necessary to execute a multiplex mapping project are contained in the following paragraphs. Refer to the manuals indicated in the text for a detailed discussion of the various phases.

34. Planning the Project

Each mapping project is a separate undertaking, requiring a complete operational plan for its satisfactory accomplishment. The planning of the project is normally executed by headquarters. The factors that affect planning are:

a. Selection of Areas to be Mapped.

(1) Request for mapping.

(2) Evaluation of need. All requests are analyzed and correlated to evaluate the priority rating.

b. Schedule of Production.

(1) Priority of project.

(2) Maintaining the balance of workload.

(3) Mapping capacities.

c. Specifications.

(1) Scale and contour interval. The purpose for which the map is to be used is the deciding factor.

(2) Flight altitude, focal length, and scale of aerial photo-

ing control, both basic and supple-

nanuscript procedures (see TM 5–240).

35. Preliminary Preparations

After the basic plans of the project have been established, there are certain data which must be procured before actual stereocompilation can be started.

a. Procurement of Aerial Photography.

(1) Types of photography.

(2) Specifications for photography. These define the technical characteristics of the photographs, the equipment (including the camera and lens) to be used, quantities needed, and procedures to be followed.

(3) Planning of photographic projects. The principal elements to be considered are the direction of flight lines, the flight altitude, and overlap (forward and side), and the extent of the area.

(4) Inspection. Prior to acceptance, all photographs are checked for conformance with specifications (see TM 5–243).

b. Procurement of Source Materials.

(1) Source materials consisting of maps, plans, diagrams, charts, trig lists, population statistics, railroad time tables, atlases, etc., should be procured and evaluated as to their extent of usage.

(2) The maps and other source materials are supplied to the multiplex compiler with recommendations for their use as supplementary aids to assist in identifying features on the photographs.

c. Procurement of Basic Control.

(1) A basic network of precise geodetic horizontal control is the first requirement in the compilation of accurate maps. These precise networks of control form the rigid framework for all types of mapping, making it possible to correlate mapping over extensive areas. This basic control may be obtained by either geodetic triangulation or traverse; of the two methods, triangulation is the most efficient and is used wherever possible.

(2) To satisfy the vertical control requirements, precise geodetic leveling is required. Geodetic level networks throughout an area are as important in topographic mapping as are the horizontal control networks.

d. Procurement of Supplemental Control. The basic networks of precise geodetic control usually do not provide all of the control necessary for multiplex mapping. Supplemental control (usually selected picture points) are required to adequately control the multiplex models. Usually, less expensive surveys of a lower order accuracy will be used to establish supplemental control, depending upon the accuracy of the mapping required. Additional information concerning field surveys may be found in TM 5–234.

36. Preliminary Operations

Before the three phases of multiplex mapping—orientation, triangulation, and compilation—can be performed, there are certain other preliminary operations necessary to compiling the map. These operations, discussed below, should be started immediately upon receipt of the aerial film and should progress as the information becomes available.

a. Processing of Aerial Film. Aerial film must be processed, developed, and handled to prevent distortions (see TM 5–243).

b. Processing of Diapositives. The diapositives represent the photography with all its high precision. The processing of the diapositives must be done with great care so that they will be accurate reductions of the original negatives. Exposure and development of each one must be accurately timed; this necessitates handling each diapositive independently to achieve the best results. The images on each diapositive must be uniformly clear and have good contrast so the detail in the models will be clearly defined.

c. Index of Aerial Photographs. On receipt of the aerial photographs, an index of the photography should be prepared. For details on the preparation of a photographic index. See TM 5–243.

d. Preparations for Field Classification Surveys. Upon receipt of the photographs, an operational plan should be made for a classification survey party. This group of field men is responsible for all detail not readily discerned from the photographs such as boundaries, names, road classification, questionable features, etc. Source material such as state and county maps, road maps, census and postal guides should be obtained and incorporated into the plan. In foreign areas of mapping, this operation is often taken over by the native country. Where it is impossible to send a field party or obtain the information from native field parties, it is necessary to obtain the additional information from the best sources available. See TM 5–234.

e. Master Progress Overlay. A master progress overlay at a convenient scale, usually at the scale of a photographic index, is prepared. The overlay should contain a reference such as the grid or the lines of latitude and longitude on which the multiplex compilation sheets, publication sheets, photo centers, and available control are outlined. Such an overlay serves as a ready reference as well as a record for work progress.

f. Plotting Sheets. For the preparation of plotting sheets, a stable base material should be used. The material should have a surface which is readily adaptable to ink and pencil, and should maintain a consistent scale under adverse climatic conditions. A [illegible] graphic projection are constructed. For details on the preparation of a compilation base, see TM 5–240. The size of the manuscript is dependent upon the plotting scale, the number of models to be worked by each operator, and/or the length necessary to accommodate the extension of control through a strip of photographs.

g. Transferring Control to the Photographs. All control points must be transferred to the photographs to facilitate multiplex operations. The normal procedure is to mark the horizontal control points on the odd or even numbered photographs, and to mark the vertical control points on the alternate or even numbered photographs. The exact position of each control point is transferred from picture to picture and from strip to strip where applicable. This must be done for all control, whether ground control established by geodetic methods, or photogrammetric control established by multiplex extension of bridging methods (stereotriangulation). Station descriptions, elevations, positions, and all other pertinent data should be tabulated on the back of the appropriate photographs.

h. Accuracy. All these operations must be completed before the multiplex compiler can begin orienting and compiling the models. Triangulation can proceed as soon as the basic control is available. It is only by careful and thorough preliminary operations that each mapping project will be accomplished with as much economy and little wasted time as possible. The accuracy of the finished map will reflect the degree of accuracy with which each phase of its preparation was accomplished.

CHAPTER 5

ORIENTATION

Section I. INTRODUCTION

37. Principle of the Spatial Model

In the multiplex model the natural terrain features are recreated at a miniature scale by the optical projection of overlapping photographs (fig. 12). To create the model, two adjacent projectors must be properly oriented with relation to each other so that they will duplicate the geometric relationship between the rays of light that existed at the instant each photograph was taken, each ray being in correct relationship to every other ray in the projection. The model is formed when all corresponding light rays from the two projectors intersect in space. These ray intersections are all in the same horizontal plane for those points having the same elevation above datum. A series of horizontal planes, passing through the model and spaced at infinitely small distances apart, contain all the intersections of corresponding rays of a correctly oriented model. The map datum is parallel to the table on which the apparatus rests, and the model as a whole may be tilted with respect to the datum without disturbing the relative positions of the projectors. This tilting of the model as a whole is termed leveling. Contours can be traced in a properly leveled model by following the images of ray intersections which cut the model at vertical spacings equal to the desired contour interval. The individual projectors of a properly oriented model assume the same relative positions that the aerial camera had during exposure. The spacing between the projectors is called the "base," which, in miniature, is equivalent to the air base between corresponding exposures. Each projector is rotated about its x axis (x tilt), y axis (y tilt), and z axis (swing) the identical amount that the camera was rotated at the instant of exposure. The distance between the front (projection) node of the projector and a plane corresponding to sea level datum is equivalent in scale to the altitude of the airplane above sea level at the time of exposure.

38. Procedure

The orientation procedure is divided into interior orientation and exterior orientation. The latter is subdivided into relative and absolute orientation.

39. Preliminary Steps of Interior Orientation

a. Remove cooling tubes from projector air hose fittings.

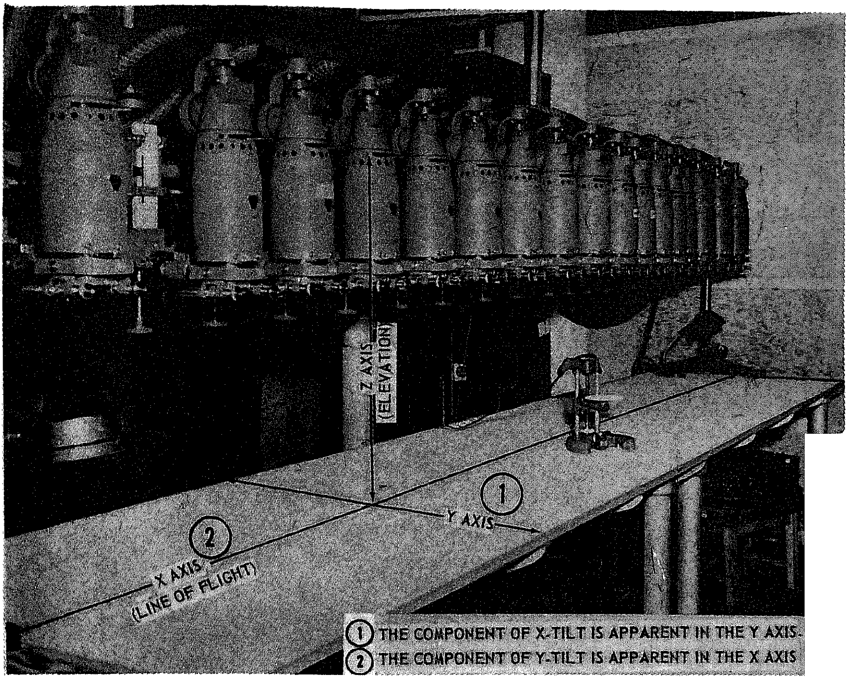

Z AXIS (ELEVATION)
①
Y AXIS
②
X AXIS (LINE OF FLIGHT)
① THE COMPONENT OF X-TILT IS APPARENT IN THE Y AXIS
② THE COMPONENT OF Y-TILT IS APPARENT IN THE X AXIS

Figure 12. Axes of orientation for spatial model.

b. Remove the lamp houses from all the projectors. The bott rims of the lamp houses are likely to leave black marks where they are set down; therefore, care should be taken never to set the lamp houses directly on the compilation sheet.

c. Loosen each swing-lock screw and rotate the projectors until all the diapositive centering mechanisms are similarly oriented.

d. Before inserting any diapositives, carefully blow or dust any dust or chips of glass from the projector lens.

40. Inserting the Diapositive

a. Lay out contact prints in the desired order with the overlapping portions of the photographs adjoining each other. Lay out the diapositives, emulsion side down, in the same order and with the same orientation. Then simply rotate each diapositive 180° when placing in the projector to allow for the fact that in projection the image is reversed left for right and top for bottom.

b. Having placed each diapositive in its projector, emulsion side down, clamp it securely. Care should be taken to release the spring gently. Undue pressure might bend or break the glass between the supporting bosses.

c. Check the diapositive for contact with the bosses by tapping it lightly with the eraser end of a pencil on each corner. If the contact is good, no clicking of glass against the boss will be heard.

d. Check the diapositives for contact with the tapered diapositive stops by slipping a thin piece of paper between glass edge and stop. If contact is good, the paper will not pass through.

41. Centering the Diapositive

Replace the lamp assembly and release the centering arm until it comes against its stop. Either on the platen or the table, observe the image of the black dot on the reticle of the centering arm, and the image of the white cross or circle marking the principal point of the diapositive. Bring these marks into alinement by means of centering screws, being careful to make the final twist of the screws a positive motion, against their opposing springs. This completes the interior orientation.

Section II. EXTERIOR ORIENTATION—RELATIVE

42. Relative Orientation

Relative orientation reconstructs the same perspective conditions between a pair of photographs that existed when the photographs were taken, thus establishing a model.

43. Preliminary Steps

a. Adjusting the Lighting. When the diapositives are in place and the lamp assemblies have been replaced, it is well to check the adjustment of each bulb to see that it gives the best possible illumination.

b. Preliminary Orientation. The time required to perform orientation, both relative and absolute, may often be decreased if at the start the projectors are roughly oriented according to the best estimate of what their ultimate orientation will be. If nothing else is known, it may at least be assumed that the flight line is level, straight, and parallel to the multiplex bar and that each photograph is truly vertical. Accordingly, it is good practice to commence by leveling the multiplex frame and each projector, not necessarily measuring these adjustments, but at least estimating them with care. Set all the y slides to a uniform value, likewise the z slides. Space the projectors an average distance apart (200 to 240 millimeters).

44. Perception of Y Parallax

When corresponding images from a pair of projectors not in relative orientation are observed on the tracing table platen, components of separation will ordinarily be seen. For the purpose of this discussion of relative orientation, the model air base will be considered to be parallel to the x direction unless otherwise stated (fig. 12). The x component at any one point can be eliminated either by altering the air base (x motion of the projectors) or by changing the height of the platen. The separation then remaining at the point is y parallax (often referred to among photogrammetrists simply as parallax) which can be eliminated only by some motion of the projectors other than the x motion. When relative orientation is first begun, y parallax can be observed without the filter spectacles and will appear as a distinct separation between corresponding images. The color filters should be in the projectors, but only as an aid in distinguishing one image from the other. Images affording good contrast and ready identification should be selected, such as cleared fields surrounded by woods, or prominent roads or fence patterns. As relative orientation progresses and the color separation can no longer be perceived, it becomes necessary to view the parallax stereoscopically using the filter spectacles. Viewed in this way, y parallax appears no longer as a separation of the two images, for they fuse into one three-dimensional model, but as a y direction split in the floating mark, the apparent separation between the two dots being equal to the disagreement of the actual image on the platen. The smallest y parallax appears finally as a slight fuzziness on the dot or perhaps as a slight fringe of colors upon its upper and lower edges. Moving the mark about a small area to obtain different backgrounds, an experienced operator can detect a y parallax of 0.1 millimeter or even less.

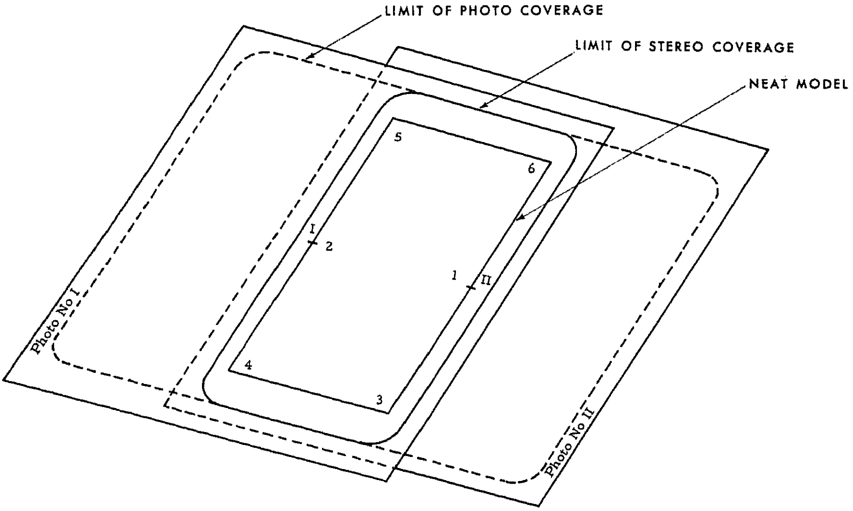
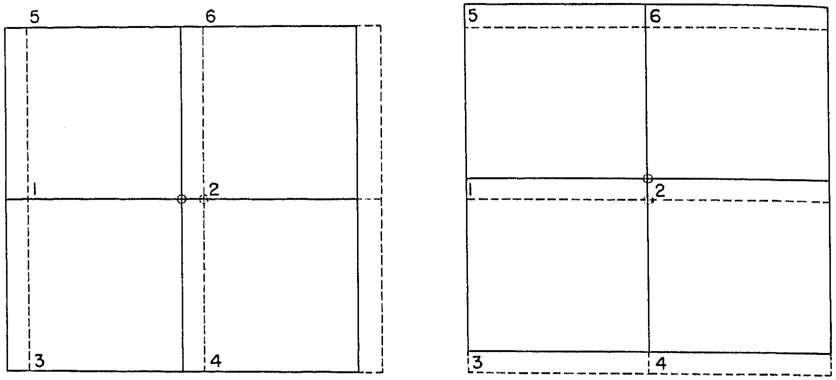
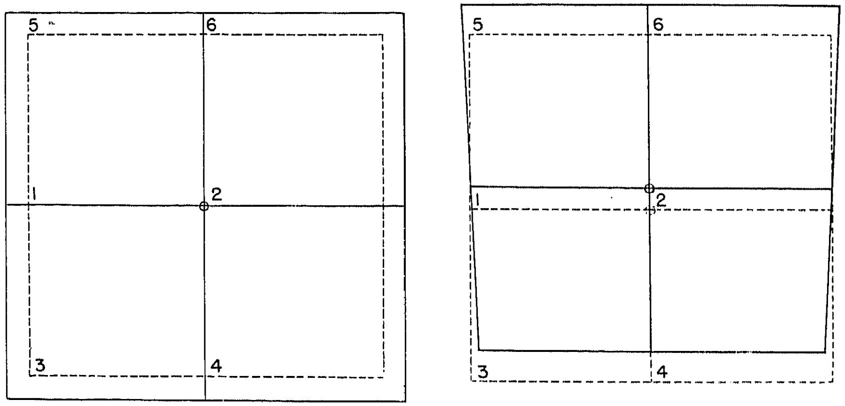


Figure 13. Dual projector method.



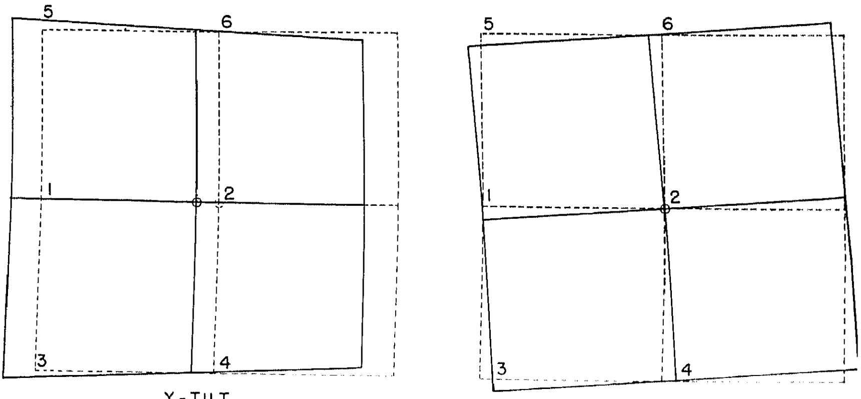
X - MOTION

Y - MOTION



Z-MOTION

X - TILT



Y - TILT

SWING

Figure 14. Effects of the six projector motions.

45. Clearing Y Parallax

The many alternative procedures for clearing y parallax are but slight variations of one fundamental procedure of relative orientation. The procedures given in this paragraph are two of the standard variations which multiplex beginners should memorize, practicing them at first using a pair of specially made diapositives having lines or dots to mark the positions numbered 1 to 6 in figures 13 and 15. The possible variations of procedure can be readily appreciated if the six motions of the multiplex projector are examined, as the effects of these motions dictate the general procedure of relative orientation. Figure 14 shows how these motions would appear to distort the true image of a grid. The plane of projection is assumed originally to be parallel to the diapositive grid plate, and the projected grid in this position is represented by dashed lines. The numbers locate the critical positions in a model at which y parallax will be observed and cleared.

a. Dual Projector or Swing-Swing Method. This method is generally used when starting a strip of several models. As this method does not make use of the translational motions, the preset values of the y slides and z slides remain unchanged. The following step by step procedure is used: (Refer to numbered positions in fig. 13.)

(1) Clear parallax at 1 with swing of projector I.
(2) Clear parallax at 2 with swing of projector II.
(3) Clear parallax at 3 with y tilt of projector I.
(4) Clear parallax at 4 with y tilt of projector II.

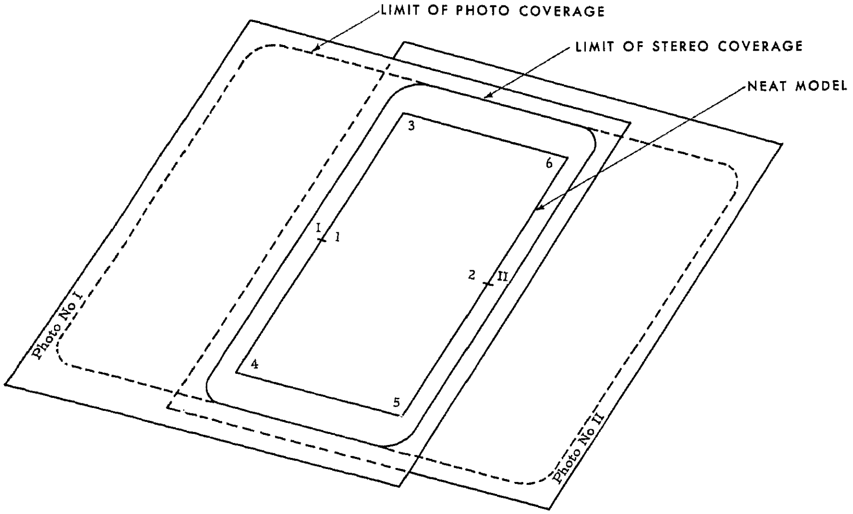


Figure 15. Single projector method.

(5) Overcorrect parallax at 5 and 6 (1½ times) with x tilt of either projector.

(6) Check 1 through 6. If parallax is present in any position, the entire procedure should be repeated until all positions have been cleared of parallax.

b. Single Projector Method. When one model is being added to another already in relative orientation, or when starting an initial model, it may be necessary to use the single projector method to progress either to the left or to the right. The following procedure is used to extend to the left. All motions are applied to projector I (left projector, fig. 15).

(1) Clear parallax at 1 with y.
(2) Clear parallax at 2 with swing.
(3) Repeat (1) and (2) above until parallax is cleared at these positions.
(4) Clear parallax at 3 with z.
(5) At 4, remove one-half of the parallax with z, and overcorrect remaining parallax (1½ times) with x tilt.
(6) At 1, remove residual parallax with y.
(7) At 3, remove residual parallax with z.
(8) Repeat (1), (4), and (5) until parallax is cleared at these positions.
(9) At 2, clear residual parallax with swing.
(10) Clear parallax at 5 with y tilt. The resultant vertical change may be removed by either the x motion along the bar or the tracing table.
(11) At position 6, referred to as the check corner, any apparent parallax indicates that some of the other positions have not been completely cleared. The entire orientation procedure then should be repeated until all points are cleared of parallax. When progressing to the right, all motions are applied to projector II (right projector, fig.

and 4 must be reversed with 2, 5,

The same orientation procedure is

followed.

c. Combined Methods. When it is permissible to use either method, the experienced stereocompiler may combine parts of both methods. This intermixing of the methods is often practiced, especially when the adjustments to be made are small.

46. Relative Orientation Problems

The terrain model is never a perfectly rectangular, plane surface, as has been assumed, and the projector axes are seldom truly parallel to the x, y, and z directions, respectively. Yet in most cases, the actual model is regular enough to respond normally to the standard procedures for clearing y parallax. The attainment of a parallax-free model becomes more difficult when the model presents any of the following to an extreme degree: rugged terrain, tilt of the photographs, unequal settings of the projector y slides, or water areas. The nature of the problem presented by each of these conditions is outlined in the following paragraphs and a course of action suggested; however, the operator must deduce the exact steps to be taken in any particular situation.

47. Rugged Terrain

The effect of topographic relief upon relative orientation procedures depends on both the magnitude of the relief and the distribution of the areas of high and low relief within the model. As an example of this, two extreme cases are illustrated in figure 16. One, figure 16 illustrates a hypothetical model in which the terrain surface has the shape of a cylinder whose axis is parallel to the air base and is at such a distance from it that the extension of the cylindrical surface would include the air base. The dashed lines show how a projector can assume various orientations and still permit all pairs of conjugate image rays to intersect. Thus, relative orientation cannot be determined solely by the usual y parallax effects. Unless the relative x tilt is properly set, the model datum will be warped. In lieu of y parallax observations, the x tilt setting must be determined by adjusting the motions until elevations in each of the four corners of the model read correctly. Two, figure 16 illustrates the opposite condition in which the terrain is at a much higher elevation directly under the flight line than it is along the front and back edges of the model. This condition increases the accuracy of the x tilt setting as determined by y parallax, because for a given increment of x tilt it creates a greater than normal y parallax between AB and BC. For the condition shown in 2, figure 16, the overcorrection of x tilt in the routine procedure would be approximately one-half the amount of y parallax, Py.

48. Excessively Tilted Photographs

If excessive tilts of the aerial photographs decrease the area of stereoscopic overlap so that it is not possible to make y parallax observations at the ideal positions, the difficulty of relative orientation will be increased accordingly. The strength of the resultant orientation will also be diminished. The principal difficulty caused by excessive tilts is due to the displacement of the rotational axes of the projectors from their normal orientation with respect to the air base, with respect to each other, or both. The one axis of a multiplex projector that is not disturbed by rotation of the

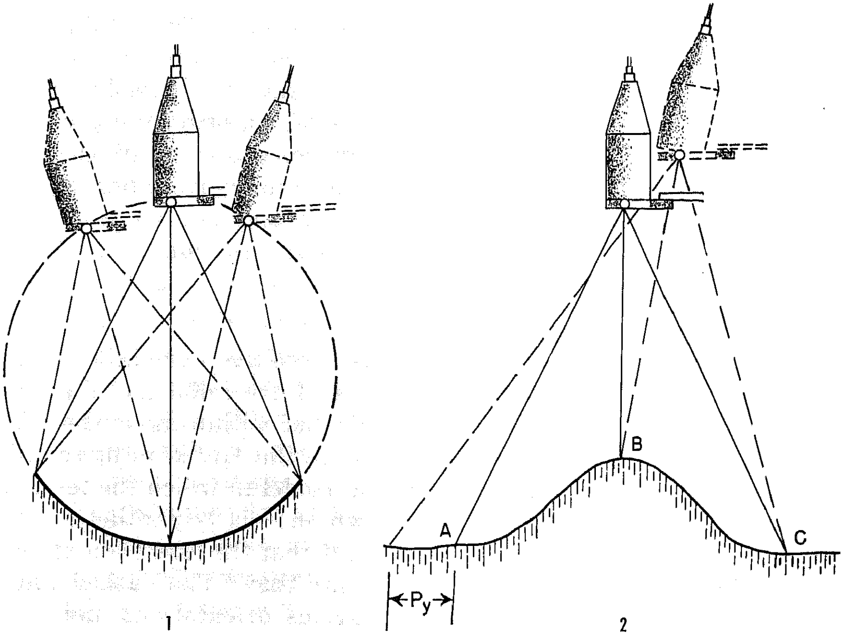


Figure 16. Examples of the effect of relief.

projector about the other axes is the y axis (primary axis). The y tilt adjustments are therefore always observed in the model at the same positions relative to the y axes. The x tilt axis can become displaced so that components of swing are introduced by the x tilt motion and the apparent overcorrection of the y parallax by this motion must be varied to allow for this. Trial and error will soon reveal whether more or less correction is required. The swing axis can become displaced in both the x and y directions, but as the swing adjustments are made prior to any other, this is not of particular importance. If it is desired that the y parallax cleared by [illegible] be reintroduced by the succeeding y tilt adjustments, swing parallax must be cleared at each nadir point rather than at the principal points. However, the swing motions (or y motions and swing) undoubtedly will be slightly interaffecting at the nadir positions, and successive trials of slight overcorrections or undercorrections of the swing settings probably will be required.

49. Unequal Setting of the Y Slides

Though it is not attributable to tilts of the aerial photographs, an excessive difference in the setting of the projector y slides also disturbs the normal orientation of the rotational axis with respect to the air base. The y tilt in effect introduces components of x tilt, and conversely, x tilt introduces components of y tilt. Relative orientation procedure is complicated by this condition which should be avoided whenever possible. If the air base must be set at an excessive angle to the bar, the logical procedure is to use, in place of x tilt or y tilt alone, a combination of the two motions calculated to produce a resultant tilt in the desired direction. Simple estimation of the proportions of each tilt motion, together with a few extra runs through the procedure, will be all that is ordinarily required.

50. Extensive Water Areas

The orientation of photography over coastal areas often is difficult because it is not possible to see y parallax in the water portions of the model. This condition is so common that every effort should be made to practice the following methods of orienting irregular models, using *full* models. The operator can then check the accuracy of his orientation by noting the errors in the portion of the model not used in the orientation procedure. Parallax which has not been removed can also be found by reading the water elevations around the model. It is obvious by an inspection of figure 17 that there is little possibility of having the usual 6 position check. The accuracy of the orientation will depend upon the operator's skill in the accurate removal of parallax from these positions that are available, and in checking the water elevations around the model.

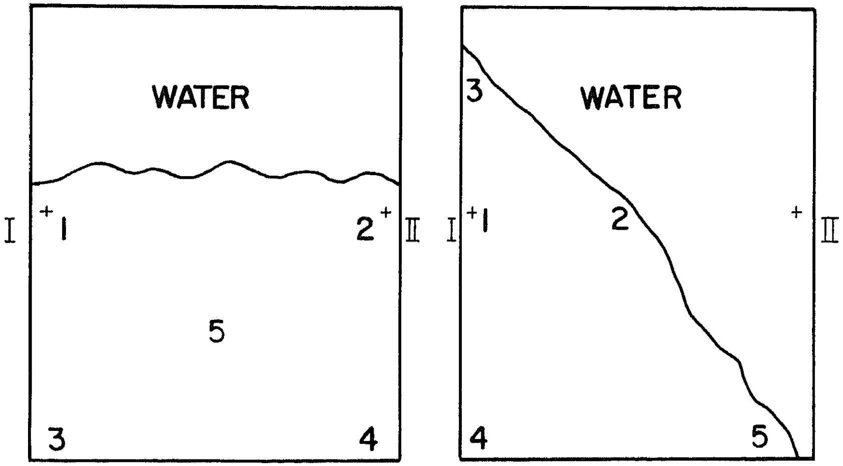


Figure 17. Examples of extensive water areas.

a. Situation 1 (1, fig. 17). All motions are applied to projector I (left projector).

(1) Clear parallax at 1 with y.
(2) Clear parallax at 2 with swing.
(3) Repeat until positions 1 and 2 are cleared of parallax.
(4) Overcorrect parallax at 3 (1½ times) with x tilt.
(5) Repeat (1) through (4) above until cleared of parallax.
(6) Clear parallax at 4 with y tilt.
(7) Overcorrect at 5 (approximately 2 times) with z.
(8) Repeat entire procedure until all parallax is removed.
(9) Check the water elevations at several points from 1 to 2.

An even slope in the water elevations across the model is caused by residual z parallax. A dished group of readings shows that y tilt parallax is still remaining. After a correction is made by using the proper motion, the parallax is removed as described, and the elevations checked again.

b. Situation 2 (2, fig. 17). All motions are applied to projector I (left projector).

(1) Clear parallax at 1 with y.
(2) Clear parallax at 2 with swing.
(3) Repeat (1) and (2) above until parallax is cleared.
(4) Clear parallax at 3 with z.
(5) Overcorrect parallax at 4 (1½ times) with x tilt.
(6) Repeat (1) through (5) above until parallax is cleared.
(7) Clear parallax at 5 with y tilt.
(8) Repeat procedure until all parallax is cleared.

Since the swing position is located near the center of the model, this point should be checked with special care. Water elevations read at several points from 3 to 5 will disclose a warped model due to remaining parallax.

c. Warped Models. Residual parallax or insufficient corrections can sometimes be localized by reading water elevations around the model. A warped model will disclose which parallax is remaining (par. 82). The motion to correct this warp is introduced and the parallax cleared by the other motions. When the model datum is flat and no parallax exists elsewhere, the model can be accepted as oriented. This orientation may not be as accurate as a full model, but it will be a better solution than a partial model.

d. Adaptations. The unlimited shapes and sizes of the irregular model cannot be fully covered in this manual. Adaptations of the methods described in the above two situations may serve as an aid in a particular situation.

Section III. EXTERIOR ORIENTATION—ABSOLUTE

51. Preliminary Steps

a. Identification of Horizontal Control. The horizontal control to which the model will be positioned may have been identified in various ways. Positions that have been established by ground surveys either are marked on the faces of the contact prints, or are identified solely by description of the points. In the latter case, the identification of several points in a group, as, for example, stations along a traverse line, can often be verified by the way in which, as a group, they correlate with their plotted positions. Horizontal pass points, or supplemental positions established by stereotriangulation for controlling individual models, will have been plotted on the base sheet either as actual points or as lines delineating small portions of planimetric features. When the stereotriangulartor has used points, he will have marked the images on the faces of the contact prints; when he has used lines, identification of the images will usually be self evident once the general locations of the features are known. The stereotriangulator may have encircled these general areas on the prints; or if the principal points are included among the pass points, and they should be, these usually serve to position the model well enough for identification of the other pass points to be made. The points selected for horizontal pass points will not necessarily be the same ones used for vertical control, although both should be located approximately at each corner of the model.

b. Identification of Vertical Control. Supplementary control points are usually encircled on the faces of the contact prints, each point being designated by a letter. Brief descriptions and the elevations of the points are shown on the back of the prints.

c. Conversion Tables. For reading elevations, a conversion table is compiled for changing the ground elevation in feet or meters to elevation in millimeters at the compilation scale. Once compiled, it serves as a handy reference for the multiplex operator, who would need to compute the change to millimeters each time a vertical control point is encountered. The following formulas give the millimeter equivalent of 1 foot and 1 meter of ground elevation:

$$1 \text{ foot} = (304.8 \times \text{Representative Fraction}) \text{ mm.}$$

$$1 \text{ meter} = (1{,}000 \times \text{Representative Fraction}) \text{ mm.}$$

Example: For plotting at 1:20,000:

$$1 \text{ foot} = \frac{304.8}{20{,}000} = .01524 \text{ mm.}$$

$$1 \text{ meter} = \frac{1{,}000}{20{,}000} = .05 \text{ mm.}$$

The ground elevation of any point can be converted to millimeters by multiplying the elevation by the millimeters in one unit of the measuring system being used at the appropriate scale.

$$10 \text{ feet} = \frac{10 \times 304.8 \text{ mm}}{20{,}000} = .1524 \text{ mm.}$$

$$10 \text{ meters} = \frac{10 \times 1{,}000 \text{ mm}}{20{,}000} = .50 \text{ mm.}$$

52. Establishing Scale and Horizontal Position

The scale of the model, now in relative orientation, is governed by the length of the air base between projectors. Scaling may be divided into two processes.

a. Approximate Scaling. Before a model can be leveled to the vertical scale of the control points, the model must be brought into the same scale horizontally. In the leveling procedure, the model is rotated about the *x* and *y* axes. Precise leveling and positioning, therefore, is not done until the model is completely leveled.

(1) Select the two horizontal control points that are most widely separated within the model. For convenience in describing this procedure, call them *a* and *b*. Place floating mark at the observed height of *a*.

(2) Without changing this height, move tracing table until the pencil is resting directly over plotted position of point *a*. Slide base sheet and tracing table until floating mark is in coincidence with image of point *a*.

(3) Place floating mark at observed height of point *b*. Pivoting from point *a*, rotate the sheet with the tracing table until the floating mark is brought as closely as possible into coincidence with plotted point *b*. The discrepancy between the image and plotted points is resolved by increasing or decreasing the size of the model. An *x* motion of projectors along the bar, equal to one-half of error at point *b*, will bring points *a* and *b* into the proper scale.

b. Precise Scaling Procedure follows generally as described [illegible] ration is performed after model has [illegible] pass points on the model are then scaled and positioned precisely.

c. Scaling Difficulties. Occasionally, a model will be encountered which, because of one error or another, cannot be made to fit satisfactorily upon all the pass points. Unless the error is so large as to suggest a need for new stereotriangulation, the discrepancy may be resolved by:

(1) Distributing the error over all points of the model.

(2) Dividing the model into segments. Compile detail from one segment at a time, shifting the position of the model

slightly for each segment. This procedure of "breaking" the model can be applied with respect to the level of the model during the contour compilation. It disposes most easily of small errors which occur despite the best efforts of everyone to build and operate equipment without error; however, it should never be used as a justification for relaxing those efforts.

The position or positions that are finally decided upon should be dropped and marked as supplementary pass points for use in checking the position of the model during the compilation process.

53. Leveling the Model

Leveling is accomplished in two steps, one being leveling in the x direction, and the other leveling in the y direction. The model may be leveled in either direction first. Two methods of leveling are available to the stereocompiler, who may choose either or combine the two. Method one uses only the motions of the projectors, the multiplex frame being stationary. Method two uses only the motion of the frame, the projectors moving in space inasmuch as they are attached to the frame and must move with it.

a. Leveling With the Projectors. In leveling by using the projectors, care must be taken that both projectors are x tilted and y tilted an equal amount. A vertical control point will ordinarily be located on each of the four corners of the model.

(1) *Leveling in the y direction.* Select the two points most nearly parallel to the y axis (fig. 12). For convenience, call these points a and b. Move the tracing table to point a and set the floating mark on the ground. Adjust the vernier scale so that it agrees with the correct millimeter equivalent of the elevation of that point. Now move to point b and set the floating mark on the ground and compare the vernier reading with the desired reading. It can be seen that the elevation of this point is either too high or too low, necessitating an overall change in x tilt. Raise or lower the floating mark an amount equal to one-half the error. Now move the tracing table with the adjusted reading over point b. Both projectors are then x tilted simultaneously until the floating mark is brought into coincidence with the ground. Parallax observed at point a or b indicates an unequal amount of x tilt. Remove this parallax by x tilting either projector. Reset vernier at point a and correct elevation. Check point b; and if discrepancy still exists, repeat the procedure until the model is leveled in the y direction.

(2) *Leveling in the x direction.* Select the two points most nearly parallel to the x axis (fig. 12). For convenience, call these points a and c. Move the tracing table to point a and set the floating mark on the ground. Adjust the vernier scale to agree with the desired reading. Now move the tracing table to point c, set the floating mark on the ground, and compare the vernier reading with the desired reading. The elevation is observed as being too high or too low. Raise or lower one projector with the z motion on the z slide an amount equal to the difference between the vernier reading and the desired reading. Remove the resultant parallax by y tilting both projectors. The amount of z introduced on the slide will not necessarily be equal to the vertical adjustment desired, but will serve as a measurement for additional changes. Repeat procedure until model is leveled in the x direction. If the control used is perpendicular to the axis of x tilt and y tilt rotations, points, a, b, and c should be in correct vertical relationship. This is seldom the case, however, so it is usually necessary to make small adjustments between all points until all read correctly.

b. Leveling With the Frame. Because leveling a model by means of the frame in no way disturbs the relative orientation of the projectors, it is generally considered the simpler of the two methods.

(1) Loosen the lock screw or lock nut to insure that no twisting stress will be put on the bar.

(2) Read elevations as before to determine the slope of the model datum in the x and y directions.

(3) Tilt the frame in the y direction as required, using equal turns of the two front screws or equal turns of the two back-foot screws.

(4) Tilt the frame in the x direction as required, using either handwheel. Instead of the handwheels, the two foot screws at either end of the frame, preferably the pivoted end, could just as well be used, turning both equally. Where A-frame end uprights are used, the foot screws are the only means of tilting the frame, in either the x or y direction.

(5) With a little experience, it is easy to estimate the number of turns of the foot screws or handwheels required to raise or lower one edge of the model by 0.1 millimeter with respect to the opposite edge. The required number of turns is dependent upon the dimensions of the model. It is in no way dependent upon the distance of the model

from either end of the frame. The inexperienced operator will find it helpful to calibrate and mark the handwheels and foot screws in terms of this 0.1 millimeter differential across the average model.

c. Leveling With the Projectors as Opposed to Leveling With the Frame. When two nonconsecutive models must be set up on the same frame at the same time, one model, at least, must be leveled using the projector motions exclusively. Otherwise, the choice between using the projectors or the frame for leveling is a matter of the operator's preference. In any case, it will generally be found expedient to use the projectors for the larger initial adjustments to avoid tilting the frame excessively.

54. Leveling Difficulties

a. Vertical Control. Sometimes a model cannot be made to agree exactly with all of the vertical control. The procedure in such a case depends on the cause of the difficulty. The identification of all points and the copying of elevation figures should be checked first to eliminate them as possible sources of error. The conversion of meters or feet into millimeters in the elevation figures should be carefully verified. If these factors are found to be correct and there is still difficulty in leveling the model, the following possibilities should be checked:

(1) An imperfect clearing of y parallax.
(2) An image distortion of some sort.
(3) An error in the control itself.

b. Warped Model Datum. If the errors of the multiplex readings on the vertical control suggest a warp of the model datum of a kind that might be due to an error of relative orientation, the operator should eliminate this possibility by further adjusting the relative tilt setting of the projectors in an attempt to flatten the datum. It is seldom possible, however, to curve a model datum more than 0.1 or 0.2 millimeter by y *tilt*, or to warp it more than 0.4 or 0.5 millimeter by x *tilt* without introducing objectionable y parallax. If greater errors than these exist, or if their patterns are irregular, the control elevations themselves should be suspected of error. Although the control elevations may be suspected of error, it is also possible that image distortion may be the source of difficulty. The operator cannot, therefore, use the model implicitly to prove the existence of an error in control. If he has field survey notes, he should check them. If no error is discovered there, it is suggested that he try setting up other models using different exposures of the same flight. Similar difficulty in leveling these models would definitely point to image distortion along that flight as the source of error; a reflight should be obtained if possible. If the difficulty is an isolated instance, new diapositives of the same exposures should be made and set up. If the difficulty is not eliminated, one of the following courses of action must be decided upon:

(1) Suspend compilation until the suspected elevations can be field checked.
(2) Determine and use multiplex elevation.
(3) Accept the control elevations and force the model to fit them.
(4) Obtain a reflight if possible.

c. Disputed Points. If a multiplex elevation of the disputed point is to be established and if the point lies along an edge or at one corner of the model, the multiplex elevation should be established by setting up adjoining models and determining the elevation of the point from all the models in which the point is visible. If forcing the model to the given elevations is decided upon, there are two possible methods. One is to divide or break the model into two or more triangular segments bounded by control, and to level and contour each as separate models. The other is to establish a local index. This is an especially convenient method for compensating small random errors in closely grouped points. The procedure is simply to index the scale of the elevation indicator of the tracing table upon one control elevation, and adjust it gradually to the index of adjacent control elevations as the contouring progresses toward them. As a rule, the operator will not continually reset the index, but will simply add or subtract small increments from each contour setting.

55. Repetition of Orientation

In general, the operations of exterior orientation are performed in the sequence in which they have been described. It is seldom possible, however, to make any setting of y parallax, model position, or model level with positive assurance that it will not be affected by some succeeding adjustment. If at any point in the procedure of relative or absolute orientation any of the preceed- [illegible] e been disturbed too greatly, it is ad- [illegible] to stop immediately and revert to the earliest setting affected and repeat the procedure from that point on. It is better still, many stereocompilers feel, to go through the entire procedure of exterior orientation two or three times, quickly at first, then more carefully, bringing a higher degree of perfection to the orientation with each repetition. As an example, it is suggested that a rough orientation be made first which will clear y parallax (without the use of filter spectacles) within 1 or 2 millimeters, level the model within 3 or 4 millimeters, and position it within

5 or 6 millimeters. A second improved orientation will clear *y* parallax within 0.5 millimeter, level the model within 1 millimeter, and position it within 2 millimeters. These are very general values, given only to suggest an approximate degree of refinement for each repetition. The stereocompiler will take but a few minutes to perform these rough orientations. The adjustments of the final, precise repetition should then be small enough not to affect each other noticeably, and all settings will be made as accurately as possible.

CHAPTER 6

MULTIPLEX TRIANGULATION

Section I. INTRODUCTION

56. Considerations

Multiplex stereotriangulation affords a means of establishing supplementary horizontal and vertical control points when relatively few ground survey control points are available. It is essential that each individual model have sufficient control information to orient it with reference to a horizontal and vertical datum. As far as conditions will permit, this information is determined by ground survey methods; but since it is usually impossible and requires an excessive expenditure of time for each model to be controlled by these methods, stereotriangulation is used to supplement the establishment of intermediate control information. To obtain this additional control, the existing control is either extended or bridged.

a. Extension of Control. The extension of control refers to the case in which existing control information is concentrated at the beginning of the strip, and the additional control must be established beyond without the benefit of known control. This is referred to as cantilever extension. There is no way of checking the accuracy of the extended portions; therefore, the method is used only when there is no other alternative, such as with "photography of opportunity" obtained during hostilities. Other problems may be encountered before such photography can be used (ch. 10).

b. Bridging Control. Bridging is the method of establishing and adjusting control between bands of existing ground control. Bridging establishes and adjusts control both horizontally and vertically. Only experienced operators should be used for this

of the whole map is relative to the

otriangulation is performed.

er Extension

When it is necessary to extend control beyond models in which established control exists, without the aid of control at the other end of the strip, the cantilever method is used. The initial models must be carefully and completely cleared of y parallax, positioned, and leveled. The remaining models are then successively brought into relative orientation and bridged to the preceding ones. Pass points are marked without further delay, because without control at the far end of the strip there is no possibility of refining the overall scale or of determining if any bow or differential scale effects are present. Vertical pass points can also be read if they are desired. BZ curves must be based on what indications are provided by the models at the "anchored" end of the strip. If no indications can be obtained, a centerline BZ curve may be assumed on the basis of the orientation of another strip by the same stereotriangulator, using controlled photography taken by the same camera. Finally, the adjustment of pass point discrepancies between adjacent strips is made in the same manner as in the case of bridged strips. The cantilever extension method is more simple to perform than bridging, but the results obtained cannot be expected to be as accurate since there is no way to check any of the adjustments made.

58. Horizontal Bridging

Horizontal bridging (stereotriangulation between control points at both ends of a strip) (pars. 60–78) is accomplished by (1) orienting an initial model accurately to given control, (2) bridging successive models each to the preceding model, and (3) adjusting the scale of the entire strip so that the scale is uniform and the setup fits all the horizontal control. When the bridge is complete, pass points are selected and marked; when two adjoining parallel strips are bridged, the pass points common to the two strips are adjusted to give a single solution.

59. Vertical Bridging

Vertical bridging (pars. 79–89) is accomplished by (1) establishing a horizontal bridge, (2) reading the elevations on pass points and ground survey control points, and (3) adjusting the multiplex elevation according to the BZ curves.

Section II. HORIZONTAL BRIDGING

60. Purpose of Horizontal Bridging

Photographic coverage of large areas is supplied in the form of parallel flights or strips. Each strip must be bridged between the lines of horizontal control that are usually placed crosswise to the flight direction at certain intervals. The exact number of models necessary to span the control interval depends on the ground distance between control and on the flight height of the photography. When each strip is bridged, pass points are plotted in the common sidelap area between adjoining strips. Finally, the pass points are adjusted by graphic resection to establish a unique position eliminating, as far as possible, those slight discrepancies between adjoining strips. The adjusted pass points will be used for the subsequent repositioning of each model for the compilation of detail.

61. Planning the Bridging Procedure

One of the first decisions the stereotriangulator must make is the order in which the several strips will be set up. The factors that enter into this decision are the amount and distribution of control and the spacing and arrangement of the flights. Preferably those strips having the most control or the most positively identifiable control, should be set up first. A study of the control plan and the flight index usually suggests a logical procedure. The next decision to be made is which model of the strip to orient first. As the horizontal control is usually confined to the end models, it is often more practical to commence orientation at either end and to proceed through the strip entirely in one direction. In any event, it is highly desirable that the initial model be one with sufficient control so that it can be completely and independently leveled, scaled, and positioned at the outset. A compromise procedure that is sometimes advisable is to assume a scale for the initial central model, correcting this scale later when the bridge has progressed to the nearest controlled model. Once one strip has been scaled, its pass points can be used to furnish the initial scale and position of any model of the adjoining strips.

62. Orienting the Initial Model

a. Short Strips. For strips of moderate length (7 or 8 models), both projectors of the initial model should be set at the midpoints of their y slides and also at the midpoints of their z slides. This is done to allow for a maximum deviation of the flight line from a straight line in any direction. The model is completely oriented relatively by the "swing-swing" method.

b. Long Strips. Setting the azimuth of the initial model of long strips (14 or 16 models) so that the flight line will not "run off the bar" often requires careful attention. The range of the z motion is not as likely to be exceeded as the range of the y motion, for the altitude of an airplane can be maintained more easily than its course. Before setting up the initial model of a long strip, it be oriented in azimuth as follows:

(1) Estimate the position of the principal point of one of the end photographs with respect to the horizontal control and spot this position approximately on the base sheet.

(2) In the same manner, spot the approximate position on the base sheet of a principal point at the opposite end of the strip.

(3) Position each end of the sheet in the y direction so that each of these positions will fall directly below a projector that has its y slide set at the midpoint.

63. Bridging Successive Models

When the initial model has been oriented as well as possible with whatever control is available, the adjoining models are successively brought into relative orientation by the one-projector method. In each case, motions are applied only to the added projector, which forms a model with one of the projectors of the preceding model. The orientation of preceding models is not disturbed. After each model is cleared of y parallax, and before the relative orientation of the next one is begun, the newly oriented model should be brought to the same scale as the preceding one by the following procedure, commonly called bridging. Viewing first the initial model (whose scale is not to be changed), select some well-defined image point common to both models, the elevation of which can be accurately read. This point should be as near as possible to the center of that area which is overlapped by both models; it will normally be close to the principal point of the center photograph. Place the floating mark at the elevation of this point. View the second model and adjust the length of its air base by an x motion (and components of y and z motion if needed) of the third projector until the elevation of the point is made equal with its elevation in the first model, as indicated by the floating mark, which is not moved. Now all the models in the strip are bridged, each in turn, to the preceding one.

64. Stereotriangulation With Two Projectors

Although the length of a strip that can be set up is definitely limited by the length of the multiplex frame, it is not necessarily limited by the number of projectors available. If necessary, stereotriangulation can be performed by using only two projectors by *leap-frogging* one projector past the other as the successive models are oriented. The scale of the initial model is passed along by bridging successive models as usual, except that the elevation of the tie point used in each bridging operation must be read and recorded in one model before the trailing projector is removed to be used in orienting the succeeding model. Leap-frog procedure also necessitates the marking of pass points from each model as it is set up. Errors of closure upon the control at the terminal end of the strip must be distributed among the intermediate positions and elevations by analytical methods. Graphical methods employing correction curves for each coordinate component of error are preferred, but least-square computations similar to those used in adjusting closure errors in traverse lines can be used.

65. Accuracy of Leveling Orientation

It is not essential that the initial model be precisely leveled. Even if it were to be carefully leveled, it is unlikely that the succeeding models would maintain level data. The probability is that the datum of each model would show a rather consistent downward "break" from the preceding one, so that the datum of the whole strip would be arched upward in the center. The vertical bow is chiefly the result of a small residual lens distortion and is the most persistent deformation of a multiplex strip. The only requirement of leveling is that no model of the strip be out of level more than the limit required for good planimetric accuracy which, depending on the amount of relief in a model, may be as much as 10 millimeters across the width of the model. Because of the severity of vertical bow in some instances, it is recommended, especially if the initial model is not a central model, that the multiplex frame be used to level the strip as a whole between vertical control at either end of the strip. This should be done after all the models have been brought to a uniform and approximately correct scale.

66. Adjusting the Orientation

The control extension operator places the diapositives in the proper projectors and performs the interior orientation and illumination adjustments. The first projector is swung where the line joining the projection of the fiducial marks on the x axis forms an angle with the true x axis (in this case the line of the frame bar) equal to the angle between the axis of the first photograph and the mean line of flight. The first projector is usually set with both its z and y movements in the middle of their range as a first approximation. When the position of the strip with respect to the mean line of flight permits a better approximation of the y movement, this should be used. All projectors are then roughly oriented relatively to insure further that all projectors remain within the limits of the y and z motion. When an erroneous assumption is made regarding position of the y and z slides of the first projector and the extension cannot be kept within the limits of the movements of the projectors, another approximation of the position of the y and z slides of the first projector is necessary, and the rough

67. Adjusting Scale

a. Procedure. Because a very small error in the scale of the first model will accumulate to a much greater error in the long extension of several models, it is likely that, even though the initial model was most carefully scaled, the length of a strip will need further adjusting in order to fit between the control at the ends. This adjustment of the overall scale of a multiplex strip is similar to the method of scaling an individual model, with the exception that the adjustment must be apportioned among the several models, as described in the following procedure:

(1) Select one well-defined control point in each end model. For convenience in describing this procedure, call them point *a* and point *b*.

(2) Set the floating mark at the observed height of point *a*, then move the tracing table and place its pencil over the plotted position of point *a*.

(3) Slide the base sheet and the tracing table with it until the floating mark is returned to coincidence with the image of point *a*. Point *a* is now directly over its plotted position.

(4) Set the floating mark at the observed height of point *b*, then move the table and place its pencil over the plotted position of point *b*.

(5) Pinning the base sheet to the table with one finger over point *a*, rotate the sheet and the tracing table with it until the floating mark is in line with points *a* and *b*. Note the discrepancy then remaining between the model position and the plotted position of point *b*.

(6) Divide this discrepancy by the number of model widths between points *a* and *b*. Lengthen (or shorten, as required) the air base of one model by this amount. Presumably the model containing point *a* will be used, although any model could be used.

(7) Rebridge all the models, bringing them to the scale of the model adjusted in the previous step.

(8) Repeat the procedure if necessary, until the strip is scaled between point *a* and point *b*.

b. Alternate Procedure. The adjustment in *a*(6) above is extremely critical and any method of increasing its accuracy is worthwhile. A change in the length of an air base probably can be accurately gaged by measuring the resultant vertical movement of the model. An alternative procedure to *a*(6) above is: viewing any well-defined image point in the model, change the air base by an amount such that the point is raised or lowered, as required, an amount equal to Δz, which is given by the expression:

$\Delta z = \frac{H \times E}{L}$ where E is the error in length at point b; H is the average projection distance; and L is the distance between point *a* and point *b*. By reference to figure 18, Δz can also be determined graphically as follows: from the intersection of the arc representing the number of model widths between *a* and *b* with the arc representing the average air base length, follow a radial line toward the origin of the graph until it intercepts the known value

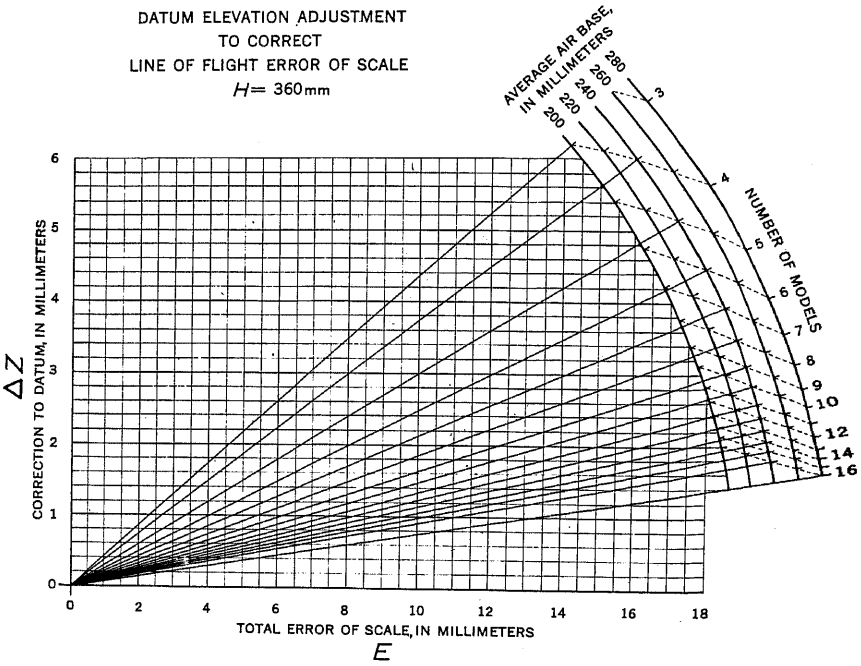
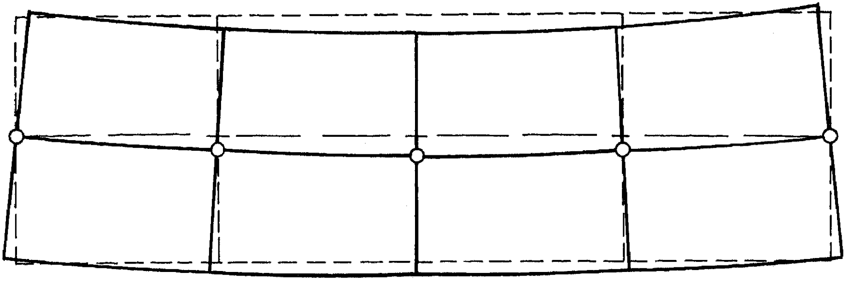


Figure 18. Scale correction by adjustment of datum elevation.

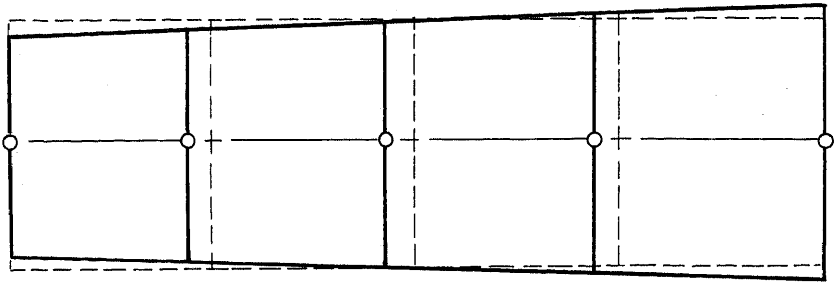
of the total error, E, on the abscissa scale. Read the datum adjustment, Δz, at this point on the ordinate scale.

68. Horizontal Deformations

a. Principal Errors. The principal errors affecting the horizontal datum of the strip are: z motion error, bridging error, and swing error. Error in z motion will cause a slight but progressive difference in the scale of one end model appearing too small with respect to its control while the scale of the other end model appears too large. If there is a control point in the center of the strip, differential scale will cause a discrepancy there in the x direction. Assuming a limit of 0.1 millimeter of y parallax in every neat model, the maximum amount a point in the center of the strip could be in error is 0.033 N^2 millimeter, where N is the number of models in the strip. Bridging error, strictly speaking, is not one of relative orientation. However, a repeated "break" in the bridge, such as shown in figure 19, will have essentially the same effect as a repeated z motion error. The effect of a 0.1 millimeter break in each bridge is approximately one-fourth the magnitude of the effect



HORIZONTAL BOW



DIFFERENTIAL SCALE

Figure 19. Horizontal bow and differential scale effect.

of z motion error specified above. Swing error causes the datum of the strip to be deformed in a "horizontal bow," which, like the vertical bow, is roughly circular. This effect is also shown in figure 19. Horizontal bow is indicated by the end models appearing to be slightly swung, in opposite directions, with respect to their control. If there is a control point in the center of the strip, bow will cause a discrepancy in the y direction there. With a limit of 0.1 millimeter of y parallax in the neat area of every model, the maximum possible middle ordinate of the horizontal bow is approximately 0.025 N^2 millimeter, where N is the number of models in the strip. An error in y motion has no cumulative effect. There are, therefore, but four different deformations of the multiplex strip; two vertical—twist and vertical bow; and two horizontal—differential scale and horizontal bow.

b. Correcting Horizontal Deformations. There is no reason to suppose that errors on the part of the stereotriangulator in orienting and bridging the models will consistently be of a kind that would accumulate to produce an appreciable horizontal deformation, although this is not impossible. One known cause of both bow and differential scale is tangential distortion in either the camera lens or the printer lens. Every precaution is taken in the assembly of these lenses to prevent this distortion; nevertheless, it is occasionally encountered. Therefore, when the strip has been scaled between two points, all the other horizontal control points that can be seen in the strip should be examined, looking particularly for indications of a consistent trend in any discrepancies. If the strip does not agree with the control, but appears to be deformed in either or both of the patterns of figure 19, it is suggested that the stereotriangulator eliminate his orientation as a possible cause by testing each model for the presence of those residual y parallaxes of errors of bridging that might be capable of causing the particular horizontal deformation that is evident. Assuming that the relative orientation and bridging operations were done to the best of his ability in the first place, the stereotriangulator must do more than simply take another look at the models. He must test them by actually moving each projector very slightly, being desirous of accumulating a small amount of swing, z motion, or bridging error in a direction calculated to oppose the observed deformation of the strip. By rocking each motion through the range within which he can see no change in the y parallax (because of the limitation of visual acuity), he can adjust each motion just short of the point where y parallax commences to be discernible. What he achieves is an orientation of the strip that is very slightly prejudiced in a manner tending to offset the effect of the error. This procedure should not be allowed to introduce any noticeable y parallax, or to overcompensate the deformation, although undercompensation may have to be accepted. If some deformation still remains, it can safely be attributed to a distortion beyond the stereotriangulator's control. If there had been any intermediate control points, bow and differential scale errors might have been minimized by *breaking* the strip; that is, by scaling it in two or more segments using each intermediate point as the end of a separate bridge rather than simply as a pier in a longer bridge. Finally the procedure of adjusting the pass points to correct for differences between adjacent strips must be relied upon to eliminate any remaining error.

69. Selecting, Marking, and Adjusting Pass Points

a. When the strip is scaled and the optimum-control solution has been obtained, pass points are selected and plotted on the base sheet. These points should be located in the corners of each model and at such other positions as are necessary to provide points in the corners of the models of the adjoining strips. It is best, therefore, to select these points after an examination of the photographs of all these strips. Pass points may be actual points, such as lone trees or intersections of lines, or they may be carefully drawn outlines of well defined features such as sharp bends in roads or streams. The principal point of each photograph should also be plotted at this time. These are useful if the models are not to be preserved intact and so have to be reoriented later for compilation of detail. Pass points should be plotted and drawn with utmost care. Although the miltiplex elevations of the points may be far from correct, the floating mark must be placed exactly on the model surface when plotting or checking the position of any points. If this is not done, the perspective nature of the image projection will result in an erroneous position being marked.

b. All the pass points except those around the perimeter of a project will have their positions determined from two adjoining strips, and small discrepancies in these duplicate positions are likely to be noted. These discrepancies should not be large—their magnitude depending more or less on the length of the strip—but nevertheless a unique position for each pass point must be decided upon. A median or simple average position should be marked unless one strip is felt to be stronger than another owing to the distribution of control, or unless an analysis of the discrepancies between several adjoining strips suggests a more plausible adjustment. In such cases, the position finally marked for each pass point must be a weighted average.

70. Adjustment of Horizontal Positions Between Parallel Strips

a. The simplest method of adjustment of the horizontal positions plotted from a series of parallel strips is to place the base sheets in their correct relationship by matching the grid lines, then prick the mean plotted position of those points common to two strips. This method is used when only two strips are extended, or when more than two strips are to be adjusted and the deviations (distance between the two plotted positions of a point determined from two adjacent parallel strips) are all small. However, if three or more strips are to be adjusted simultaneously, the deviations are usually large enough to warrant a graphical-block adjustment.

b. The graphical-block method of adjustment of the horizontal positions gives an adjustment of each strip based on the mean of all strips in the adjustment. In this method, it is assumed that the discrepancy between the two plotted positions for each point in the overlap zone of two strips is caused by an error in scale and an error in azimuth in each strip while setting up the multiplex extensions. The errors in scale cause displacement co nents that are perpendicular to the mean line of flight. Whe control has been extended for several adjacent, parallel s the mean line of flight for any one strip is used as a co line for the measurement of the two components of the deviat A line perpendicular to this control line, through the prin point for the second projector of the strip used in determ the control line, is used as a base line from which the leng each extension is measured. Within the overlap between adj strips, the two components are measured for the deviation bet the two plotted positions for each point. The mean distance the base line of the two plotted positions of each point is measured. The procedure is best described by use of an exa

(1) Consider that an extension of control is made for parallel flight strips. Let these strips be numbered 1, 4, and 5. Suppose the control line to be the mean li flight for strip number 3, then the base line is perpen lar to this line, through the principal point of the se picture of strip 3. Two correction graphs (fig. 20 drawn as explained below.

(2) To construct the scale correction graph, each poi the overlap between strips 2 and 3 is represente

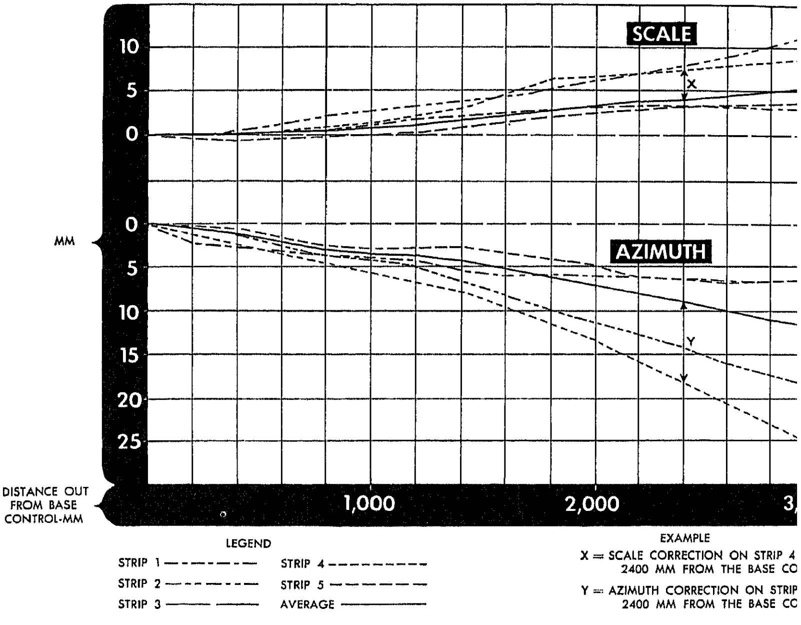


Figure 20. Typical curves used in adjusting the scale and the azimut five-strip extension.

plotting the deviation component due to scale as the ordinate, and the mean distance from the base line to the plotted position as the abscissa. The adjacent points are connected by straight lines on the graph. The points in the overlap between strips 1 and 2 are represented on the graph in the same manner except the ordinates are measured parallel to the line formed for the overlap between strips 2 and 3. These adjacent points are connected with straight lines. Points in the overlap between strips 3 and 4 are represented on the graph in the same manner as for those in the overlap between strips 2 and 3, and lines are drawn connecting these adjacent points. Points in the overlap between strips 4 and 5 are represented in the same manner as for the overlap between strips 1 and 2 except the ordinates are measured parallel to the line plotted for the overlap between strips 3 and 4. A mean line for *five* plotted lines is then determined and drawn on the graph. This line is the mean for the four lines (described above) and the zero ordinate line.

(3) To construct the azimuth correction graph, four lines and the mean for five lines are plotted to represent the deviation components due to azimuth errors. These lines are plotted in the same manner as described in (2) above, except that the deviation components due to azimuth errors are plotted as the ordinates.

(4) When using the correction graphs, the plotted positions of the points (on the plotting sheet) are adjusted by values measured on the two graphs. In measuring the adjustment values, all measurements are made from the mean line. The distance to the zero ordinate is the correction for all points in strip 3. Corrections for all points in strip 1 are measured to the line plotted for the overlap between strips 1 and 2. Corrections for all points in strip 2 are measured to the line plotted for the overlap between strips 2 and 3. Corrections for the other two strips are obtained in the same manner from the other two irregular lines.

71. Adjustment of Horizontal Positions Within a Bridge

The adjustment of horizontal positions in a bridge is most readily accomplished by adjusting the scale of the multiplex strip and by shifting the acetate plotting sheet to the position giving the best average correspondence between the fixed control points in the models and those plotted on the sheet. As shown in figure 21,

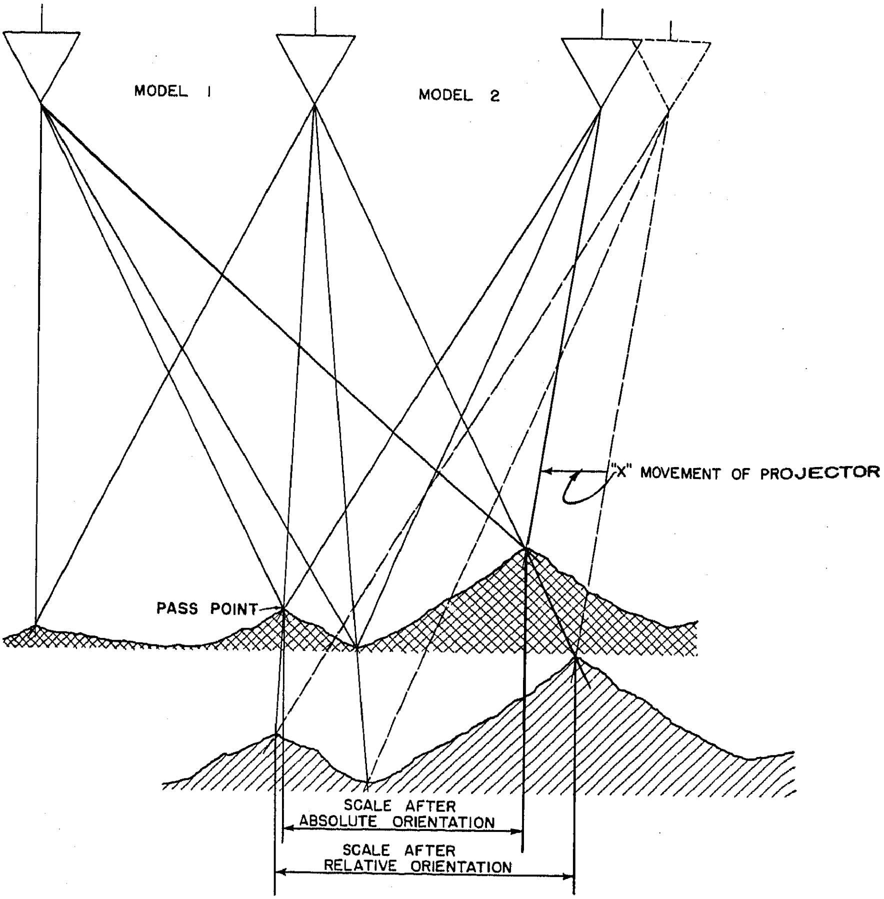

MODEL 1
MODEL 2
"X" MOVEMENT OF PROJECTOR
PASS POINT
SCALE AFTER ABSOLUTE ORIENTATION
SCALE AFTER RELATIVE ORIENTATION

Figure 21. Altering the scale of the model.

when the scale of the model is altered by an x movement of one of the projectors forming the model, the height of the model above the multiplex table is changed. This relationship between the change in the height of the model and the change in scale may be used to adjust the scale of a strip. The amount of change in height of the model to correct for an error in scale equals the percentage of scale error multiplied by the projection distance. The height of the first model of the strip is changed the necessary amount by an x movement of the second projector of the strip, then other models of the strip are scaled successively to the preceding model by making the elevations of the center pass points the same in adjacent models. If the proper scale is not attained on the first trial, the procedure is repeated.

72. Horizontal Control Extension by Stereotemplet

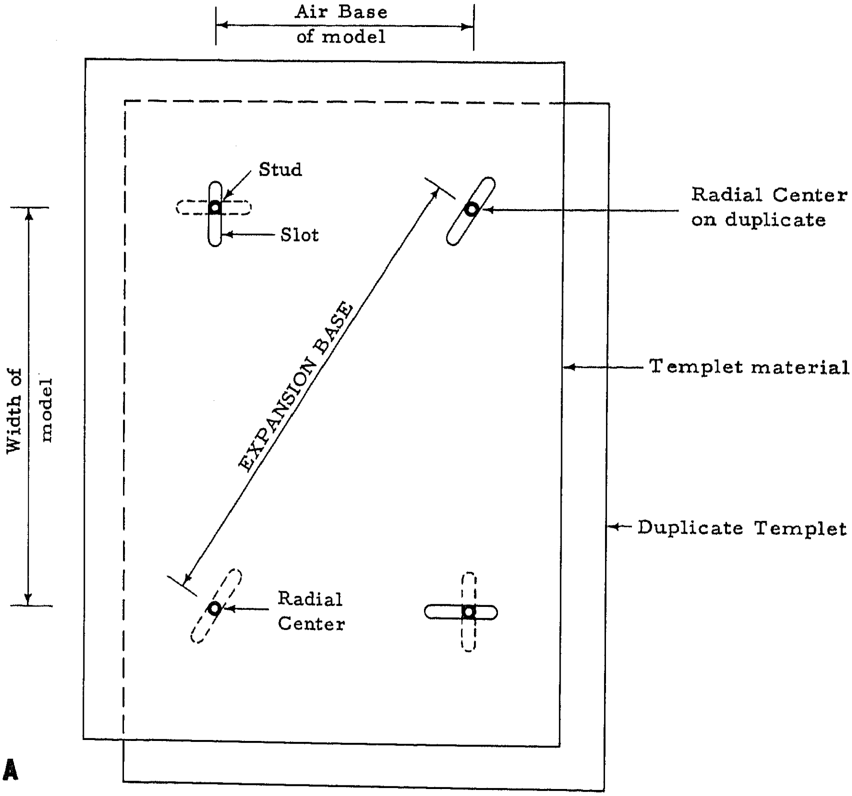
A stereotemplet is a composite slotted templet which represents mechanically the horizontal position plot of a stereoscopic model. It combines the geometric strength of the stereoplotting technique with a templet system that permits an area solution.

a. Positional Data Required. The positional data required for the preparation of the templet are stereoplotted from geometrically faithful optical models formed in the instruments. Positions of image points plotted orthographically from leveled models are rectified with respect to tilt and have no horizontal displacement due to relief. The positional data furnished to the stereotemplet is, therefore, at a random but uniform scale. The only function of the stereotemplet is to maintain this scale relationship between any and all points plotted from a single model while allowing for the enlargement or the reduction of the overall scale of the templet. The stereotemplets are adjusted to the desired common scale when the templets are assembled to satisfy horizontal control positions.

b. Model Datum. The datum of a model from which a stereotemplet is to be prepared must be leveled to the tolerances necessary to maintain the proper planimetric relationships to positions plotted orthographically from the model. The stereoscopic model provides the operator with an excellent means of observing, comparing, and measuring the elevations of physiographic features within the area. All stereoscopic plotters are equipped with the means of adjusting the model to a desired orientation. Where vertical control is available, the datum of the model may be quickly oriented to within one degree of a horizontal plane. In lieu of known elevations, hydrographic features such as swamps, lakes, and major drainage provide information useful in eliminating the excessive tilt of a model datum. Where the photography has been flown in accordance with specifications that limit tilt and flight height variations, the spatial orientation of the projectors furnish data usable in limiting the inclination of the model.

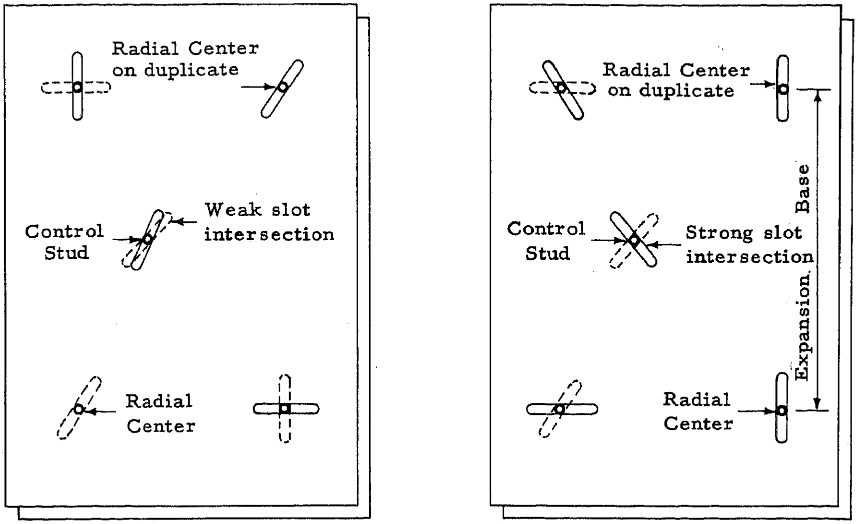
c. Templet Construction. With the exception of the stereoscopic plotter, the equipment necessary for the preparation of stereotemplets is identical with that used to prepare conventional slotted templets. Hard pressed cardboard, .03 inch thick, has the rigidity necessary to resist deformation and has proven to be a satisfactory templet material. A stereotemplet, illustrated in A, figure 22, is prepared by stereoplotting all relevant horizontal control and preselected pass point positions onto the templet material. These positions are pricked through to another section of templet material to form a duplicate. Each templet will contain a minimum of four plotted positions, representing image points, in each of the four corners of the respective neat stereoscopic model. A stud-fitting hole is punched at one of these model corner positions. Stud-fitting slots, containing the other positions plotted from the model, are cut radially from the corner hole. In the duplicate section of the templet material, the stud-fitting hole is punched at the position of the pass point representing the diagonally opposite corner of the model. Slots, containing the positions of all other points, are cut radially from this hole. The two sections of the templet are then identically oriented and one superimposed upon the other. Studs, that are to represent model image points, are placed through the holes and slots. This composite is referred to as a stereotemplet. The scale of the stereotemplet may be varied as needed. Each stud will move a proper proportional amount to satisfy any necessary scale change imparted to the stereotemplet.

d. Optional Solutions. The holes punched in each of the sections of the templet need not be diagonally opposite to each other. These are the preferred locations for the radial centers and pro-



A—Stereotemplet of a stereoscopic model

Figure 22. Preparation of stereotemplets.



Radial Centers at diagonally opposite model corners.

Preferred design when control exists at or near center of model.

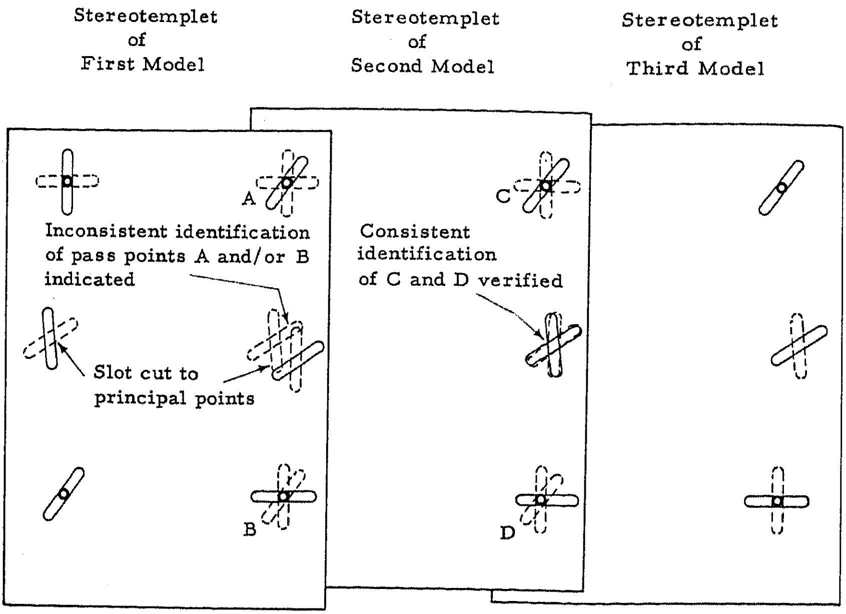
B

B—Optional locations of radial centers

Figure 22—Continued.

vide the templet with its greatest strength. The left diagram of B, figure 22 shows that when the position of a horizontal control point is plotted on or near a line connecting the two radial centers, the slots cut radially from these holes would define an ineffective angle. To assure a strong angle of intersection at the control point, one of the radial centers may, and should, be located at another of the corner positions, as shown in the right diagram of B, figure 22.

e. Principal Points. The positions of the principal points of the exposures forming the model are not essential for the construction of the stereotemplet. However, it is advisable to include their positions on the templet when the images selected as pass points are not readily identifiable. The projected images of principal points that have been printed or etched on the diapositives are of certain identification. When included on the templets, these positions are not to serve as radial centers. As shown in C, figure 22, their function is to provide a check on the exactness with which pass points common to successive models have been interpreted and plotted. Consistent identification of these pass points is verified when the two intersecting radial slots on each of the adjacent stereotemplets define a single position for their common principal point.


Stereotemplet of First Model
Stereotemplet of Second Model
Stereotemplet of Third Model
A
Inconsistent identification of pass points A and/or B indicated
Slot cut to principal points
B
C
Consistent identification of C and D verified
D

C

C—Principal point check of pass point identification

Figure 22—Continued.

f. Accuracy Advantage Over Conventional Slotted Templets. The accuracy of scale solutions that may be achieved with assemblies of stereotemplets is far greater than that anticipated or experienced with assemblies of conventional slotted templets. The basic information furnished to each stereotemplet has the greater precision of the stereoplotting technique. The conventional slotted templet, representative of a single photograph, must include among its functions the rectification of image displacements due to relief and tilt. This monoscopic consideration dictates that all slots be cut radially from a point at or near the center of the conventional templet. The elimination of rectification as a function of the stereotemplet permits its design to be stronger and more accurate.

g. Assembly of Stereotemplets.

(1) *Preparations.* Preparations for an assembly of stereotemplets are essentially the same as those required for a layout of the conventional slotted templets. A flat and rigid supporting base is necessary. Stable manuscript sheets, securely fastened to the base, are satisfactory materials upon which to plot the necessary grid lines and horizontal control positions. The scale of the assembly should be equal to or larger than the intended compilation scale. Studs representing horizontal control points are

secured to the base at their known coordinate values. To be of use in controlling the assembly, the images of these control points must be identifiable in the optical models and stereoplotted onto their respective templets.

(2) *Laydown.* The most effective pattern of the models to be used in an assembly is largely dependent upon the amount and location of the available control, and the size and shape of the project area. Where an abundance of control adds rigidity to the assembly, a considerable number of models within the area of interest may be eliminated. Where horizontal control is sparse, all models containing points of known position should be included. Where control at the perimeter of a project is lacking, the assembly may be strengthened by adding the stereotemplets of models adjacent to the area.

(3) *Extension.* The ability of the stereotemplets to retain scale and azimuth and to permit the extension of the scale in any direction facilitates the layout operation. Advantage of these qualities is taken by assembling the templets containing horizontal control first and then assembling the minimum number of templets that tie the control templets together. An immediate check of the reliability, the identification, and the plotting of the available horizontal control as well as the proper preparation of the templets included in this network is provided. This procedure establishes early the size at which the remainder of the templets are to be assembled and thereby reduces their subsequent scale adjustment to a practical minimum. It is advisable to add the remaining templets in sequences that form successive square-shaped areas. When assembled in this manner, the stereotemplets are self-checking. A failure of templet closure is often indicative of an erroneous identification or plot of a pass point common to adjacent flights. An improperly prepared templet may be readily detected and replaced with a corrected templet. After the completion of the assembly, the determined pass point positions are pricked through the studs of the manuscript sheet.

h. Advantages. The stereotemplet method has overcome many of the limitations inherent in the techniques that rely upon an independent scale solution for each of the pertinent flight strips. In an assembly of stereotemplets, the influence of horizontal control positions is not confined to the particular flight in which they are located. Although the minimum control requirements for stereotemplet solutions are not presently established, it has been demonstrated that these needs are considerably reduced, both in amount and in location, from those required for stereotriangulation. In many areas where the existing control is not suitable for stereotriangulation, an adequate scale solution may be obtained with stereotemplets. Stereotemplets provide a convenient means of combining into one simultaneous scale solution the positional information derived from photography taken at various altitudes, with cameras of different focal lengths and from vertical, low-oblique, and high-oblique photography.

73. Stereotriangulation Aids

When stereotriangulation of sparsely controlled areas must be performed, there are a number of means that can be employed to supplement ground control. These include flights crossing the regular pattern at intervals, altimetric data, tilt data, and Shoran. At present, none of these methods or devices are capable of the accuracy of ground surveys; therefore, they should be employed only when accuracy requirements permit. The methods of applying the information furnished by these aids are not as firmly established as are the more routine methods of multiplex operation. When and if the stereotriangulator has occasion to use any of them, he will probably desire to develop his own methods to a large extent. A few comments can be made regarding the functions of these aids.

74. Cross Flights

Flight strips crossing the main flight pattern serve to knit the regular or compilation strips more closely together. They supplant the usual lines of control, making most use of sparse control; thereby providing a better overall horizontal and vertical scale. The cross flight containing the control should be oriented first. This will give a more firm anchor for the mapping photography.

75. Altimetric Data

Data concerning the altitude of each exposure station can be recorded from an altimeter or a statoscope carried in the airplane. Fairly accurate indications of the relative heights of the exposure stations are sometimes obtained. A comparison of these data with the measured heights of the oriented multiplex projectors is used to adjust the overall level of a strip (in the x direction) and to furnish the necessary information for plotting a BZ curve.

76. Tilt Data

Tilt data, such as are furnished by a horizontal camera or by gyroscopic means, are most readily applicable in the operation of instruments such as the stereoplanigraph, which have calibrated scales indicating the tilts of the projectors. Multiplex projector tilts can be measured, however, either by optical means that record the tilt of the principal ray, or by a level bubble placed upon the projector. The tilt values of all the projectors in a stereotriangulated strip should be employed to determine the level and the curvature of the strip. Tilt data furnish a vertical datum both in the x and in the y direction.

77. Shoran

The Shoran system can be applied to photogrammetric mapping, since it can determine the position of the aircraft at each exposure station. Ground stations are placed at each end of a base line of known length and an aerial station within the photographing aircraft. At the instant of exposure, the airborne set measures the distances to the ground transponders. These distances are reduced to corresponding ground lengths, and the triangles are solved for positions of the plumb point. These positions, plotted on the base sheet, are nadir points directly above which each corresponding projector should be oriented. There are a number of devices that indicate the plumb ray line from each projector lens, such as vertical collimators, level bubbles, and plumb bobs. Because of the random errors in the determination of individual positions by Shoran, it is best to scale the strip as a unit, selecting the best average scale and position. This procedure of using the plumb rays of the projector requires that the models be carefully leveled. Therefore, allowances must be made for the slopes of some models due to the vertical bow of the strip.

78. Airborne Profile Recorder (APR)

The Airborne Profile Recorder, by measuring the clearance between the photographic aircraft and the terrain, provides an electronic method of obtaining supplementary vertical control. Tests are underway to provide additional information regarding the accuracy and economy of the method. It is expected that the development of optimum APR procedures, and subesquent use of these methods in production, will result in a reduction of the amount of geodetic control required for photogrammetric extensions.

Section III. VERTICAL BRIDGING

79. Vertical Orientation

Whether the purpose of multiplex stereotriangulation is to establish supplementary elevations or supplementary horizontal positions, the initial steps of orienting the models, leveling the strip, and bringing it to scale are much the same. In relative orientation, the ultimate accuracy of vertical bridging is dependent chiefly on the precision and uniformity with which this operation is performed; therefore, no attempt should be made to bias the *y* parallax solution because of horizontal bow or differential scale. Nor should the *y* parallax solution be biased in any attempt to flatten a vertical deformation of the strip datum. Slight vertical deformations are virtually unavoidable and any attempt to regulate them would undoubtedly require the introduction of visible amounts of *y* parallax into each model, a procedure that cannot be controlled with as much precision as the complete removal of *y* parallax. The correction of these errors must be done by analytical means. In leveling a strip, the very presence of vertical bow makes anything but an approximate leveling impossible. The analytical method of eliminating errors due to vertical bow and other deformations compensates at the same time for the manner in which the strip was leveled. However, for best results, the average slope of the strip datum, both from end to end and from front to back, should be made as nearly level as possible. In scaling the strip, it is not necessary that a perfect fit be obtained between the two end positions, point *a* and point *b*. The range of relief will be relatively small compared to the overall length of a strip, so that an error in length of 2 or 3 millimeters would seldom be responsible for as much as 0.1 millimeter of error in any elevation reading.

80. Reading the Elevations

Elevations of side pass points are read and recorded from the overlapping section of adjacent models of the strip. During the extension these readings should be carefully watched as a check on the accuracy of the orientation. The elevations to be read (vertical pass points) are selected to be identical with the horizontal pass points whenever possible; thus they will include one in the corner of each model plus any other points needed to control the corners of the models of adjacent strips. Points to be read also include all of the vertical control. The readings on these points indicate the probable nature of the vertical deformation of the strip datum and hence the required corrections to the readings on other points. All readings are made without changing the index of the tracing table scale after it is read on the starting point.

81. Adjusting for Cross Tilt and Bridging Error

Each corner point will be read in each of two adjoining models of the strip. These readings will reveal any relative tilt between the two model datums, also any slight error in the bridging of

82. Vertical Deformation

The cumulative effect upon the datum of the strip of a recurring error in each of the elements of relative orientation, including x motion, is shown in figure 24 (although x motion is not strictly an element of relative orientations, it is included because an error of its setting results in a bridging error, the effect of which is similar to that of z motion error). It should be clearly understood that these deformations of the strip datum refer to the way in which the control points of the strip fit upon their plotted positions; they do not refer to the actual configuration of the terrain surface, nor do they have any connection with the shape of the strip as it is governed by the path of the airplane in flight. The magnitudes of the deformations, as indicated by the differences between the solid and dashed outlines, are greatly exaggerated in figure 24. The actual magnitude of a particular deformation depends upon three factors: the magnitude of the causative error, the rate of recurrence of the error in the strip, and the number of models in the strip. The practical errors affecting the vertical datum of the strip are the x tilt and the y tilt error.

a. Error in X Tilt. Error in x tilt causes the datum of the strip to "corkscrew" or "twist"—that is, to slope progressively more and more in the y direction. This slope reverses its trend across the width of each model, but the twisting shear (called cross tilt) between successive models overbalances this reversal. Assuming every model were warped the maximum possible with a limit of 0.1 millimeter of y parallax in the neat area, the change in the y slope of the strip would average approximately 0.8 millimeter per model.

b. Error in Y Tilt. Error in y tilt causes "vertical bow." The datum of the strip as a whole bows up or down in the center, giving the effect, in profile, of a number of short chords forming an approximately circular arc. The negligible curvature of the datum of each individual model is opposite to that of the strip datum. Assuming every model to be warped the maximum possible with a limit of 0.1 millimeter of y parallax in the neat area, the middle ordinate of the vertical bow is approximately 0.05 N^2 millimeter, where N is the number of models in the bridge. If reasonable care is taken to obtain an average level for the strip, twist and vertical bow effects are not a concern of the operator doing horizontal stereotriangulation.

83. Evaluation of Extended Elevations

a. After the horizontal evaluation, elevations may be evaluated and adjusted. Two deformations normally affect the elevations.

b. The removal of y parallax through a series of projectors

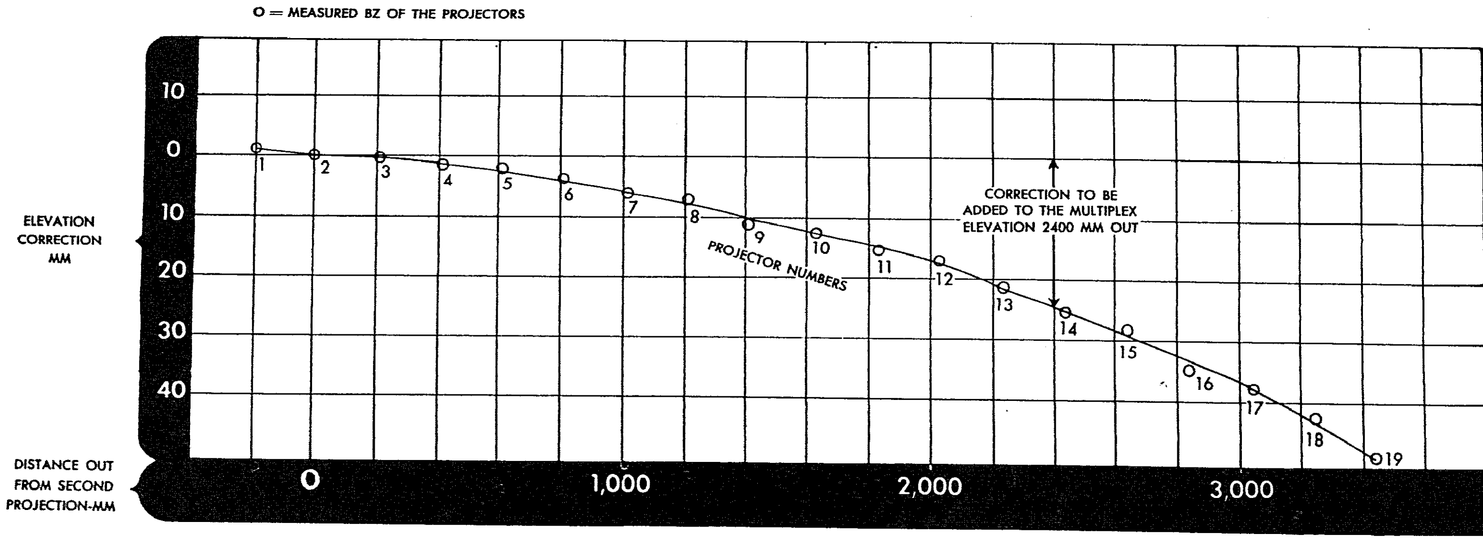


Figure 25. Typical BZ curve used to adjust elevations.

The correction for any point can be found by measuring its horizontal distance from the second projector, and reading the value from the curve at that point. Thus a point 2400-mm from the second projector would need a correction of 24-mm to bring it to a level flight.

c. The second deformation is due to residual parallax as discussed in paragraph 82. To compensate for cross tilt as well as bridging errors, the elevations of pass points and control points at the front and back of the strip in each model are read and plotted. The first control point is used as the origin for the ordinate values. A smooth curve is drawn through each set. The abscissa at any point is the correction to be applied to bring the elevations to level. For example: The back pass point opposite projector 4 (fig. 23) is read in model 3–4 as 45.7-mm; in model 4–5 as 45.9-mm. The average is 45.8-mm. However, as described in paragraph 81, the bridging adjustment is + 0.1-mm, changing the reading to 45.9-mm. After the curve is plotted, the correction shows the point to be 10.9-mm too high. This makes the corrected value equal 35.0-mm, which is used to level the model before contouring.

d. Both curves can be combined and a single correction computed for each point. Instead of measuring the projector distance and plotting a BZ curve, the index is set and all control and pass point elevations are read. Back and front curves are drawn as in *c* above. The correction for each pass point due to BZ curve and bridging errors can then be read off the graph.

84. Measuring X and Y Coordinates of the Points

A straight line is now lightly drawn on the base sheet along the center of the strip. This is a reference axis along which the x coordinate of each vertical control and pass point should be measured (units of centimeters to the nearest centimeter are convenient). The y coordinate of each point should also be approximately measured. The latter is needed only when the slope of the strip in the y direction (due to twist) in combination with excessive variation in the y coordinates of the points makes it inadmissable to assume that all points lie at a uniform y distance from the reference axis.

85. Plotting BZ Curve To Correct for Vertical Bow

Selecting suitable scales, plot on graph paper the x coordinates of the vertical control points as abscissas. As ordinates, plot the errors evident at each control point between the adjusted multiplex readings and the true values. Through these points draw a smooth curve. A spline will be helpful in drawing this curve, which is known as the BZ curve. The ordinates under the BZ curve then give the corrections that must be substracted from all the adjusted multiplex readings to correct for vertical bow and reduce the readings to sea level datum. Refer to paragraph 83 and figure 25 for multiplex procedure and plotting of BZ curve.

86. Adjustment of Elevations Within a Bridge

The adjustment of elevations in a bridge is made in the same manner as for an extension, except that the correction to be applied at the end of the bridge is known from the error of closure. The difference between the closing elevation correction and the terminal correction from the BZ curve is proportioned through the strip as a straight line adjustment. The information necessary for these elevation adjustments is obtained from the original extension (before the strip is scaled), provided the error in scale does not exceed 0.3 percent.

87. Datum Twist Correction Procedure

a. When the elevation readings indicate that the strip either twists or slopes in the y direction, two correction curves must be used. These may be either two Z error curves representing, separately, the errors along the front edge and the back edge of the strip, or they may be one BZ curve representing the error along the centerline of the strip plus an auxilliary curve showing the additional errors along the front and back edge of the strip due to slope or twist. In the event that the y coordinate of any point differs too greatly from this distance, the correction obtained from the curves must be suitably interpolated. Interpolated values should be used in plotting the Z error or twist curves as well as in obtaining error corrections from them. Figure 23 provides an example of the use of Z error curves in correcting the errors of vertical bow (y tilt) and twist (x tilt).

b. When strips covering long ground distances are stereotriangulated, the effect of earth curvature may be considerable. Its effect is to cause the datum of any strip to arch upward in a vertical bow. The height of this arch, V is given by the expression $V = 0.167\ L^2$ where V is in feet, and L is the length of the strip in miles. However, no separate calculation of this error is necessary, since the above-described method of correcting vertical bow and twist errors automatically corrects all vertical deformations of the datum, regardless of their source.

88. Adjustment of Elevations Between Parallel Strips

After the extended elevations in each of the single strips have been evaluated, an adjustment between strips is made by using the mean elevation for those points that are common to two strips.

Elevations not in the sidelap area are adjusted proportionately. Some discrepancies are to be expected in the values obtained by vertical stereotriangulation of adjoining strips. Just as a single position for each horizontal pass point was obtained by adopting a weighted average, a single value for the elevation of each vertical point is also decided upon compromising its two values. This adjusted value is determined by weighing each of the two discrepant figures after giving the consideration of the distribution of control and the probable "strength" of each strip as revealed by an examination of the discrepancies between the several strips.

a. Two short intersecting or parallel flight lines extended from rigid control should receive straight line adjustments of position discrepancies without regard to other factors.

b. Weights should be applied to adjustments of intersecting or parallel strips in inverse proportion to the distance extended from control in each strip.

c. Where conditions permit, horizontal adjustments should be made by superimposing the extension sheets on the control plot. Once adjusted, the positions may be pricked through to the control plot, for use by the operators.

d. Vertical adjustments should be performed analytically. An exception occurs when horizontalization to terrain features is made.

e. The relative positions and elevations of all points in a model should be maintained as closely as possible in the a ment.

89. Terrain Features

In the final adjustment of elevations within a strip, terrain features should be considered. Flat plains, lakes, bodies of water, and the direction of flow and the estimated slope of streams, can be used in such an adjustment. Adjustment of the strip to such terrain features should be made last. Intermediate elevations between such terrain features should be adjusted proportionately.

CHAPTER 7

COMPILATION

Section I. INTRODUCTION

90. Considerations

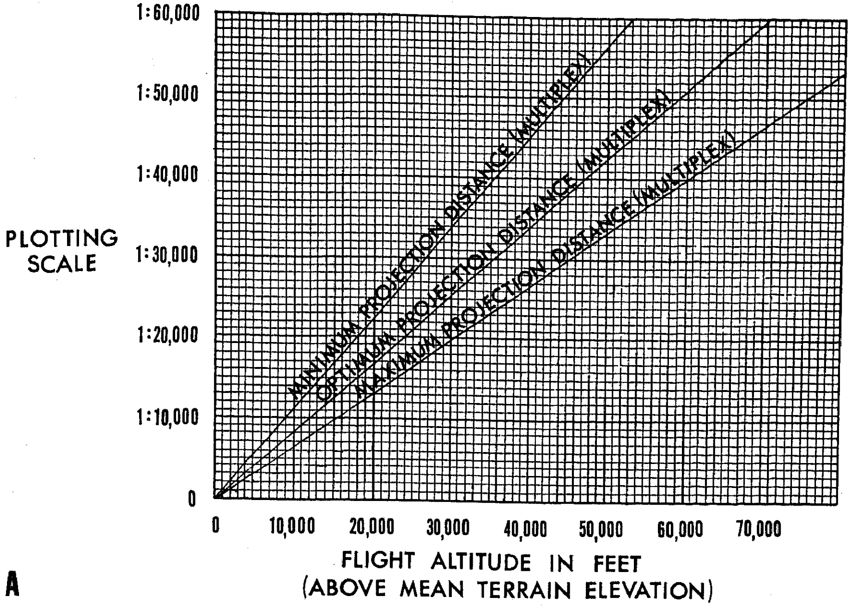
a. Definition. A map is a graphical representation, at an established scale, of a part of the earth's surface, showing important manmade and natural features in their correct positions relative to a coordinate reference system and to each other. The map may emphasize, generalize, or omit certain features to satisfy specific requirements. It may be a topographic map, which portrays the features both horizontally and vertically, or a planimetric map, which presents only the horizontal position of these features.

b. Compilation. Compilation is the process of extracting this map detail from aerial photographs and other sources and fitting it to a control network. It is the foundation of a map. The finished map can be no more accurate than its compilation, nor can it contain more information than is incorporated in the compilation. A large part of the responsibility in preparing a satisfactory map, therefore, rests squarely upon the compiler. He must exercise extreme care in selecting and plotting all detail so that the finished product will not only meet prescribed standards of accuracy, but will also satisfy the map's purpose. The amount of information shown depends on the scale, purpose of the map, and the availability of source data. The compilation process is divided into two principal phases—planimetry and contours. The planimetry is normally compiled first in each model.

91. Plotting Scale

The plotting scale is the relationship of the size of the compilation to the size of the ground area it represents. This relationship may be expressed as a linear equivalent, such as 1 inch measured on the compilation equals 1 mile on the ground. The compilation scale for multiplex is directly related to the flight altitude above mean terrain (A, fig. 26). This scale should be selected for the optimum projection distance of the multiplex projectors. The most desirable plotting scale at optimum projection distance is obtained by dividing 360-mm, the optimum projection distance, by the flight altitude in feet (converted to millimeters) above mean terrain. Thus:

$$\frac{360 \text{ mm}}{10{,}000 \times 304.8 \text{ mm}} = \frac{1}{8466} \text{ or approximately } 1{:}8{,}500.$$



A—Multiplex plotting scale and flight altitude

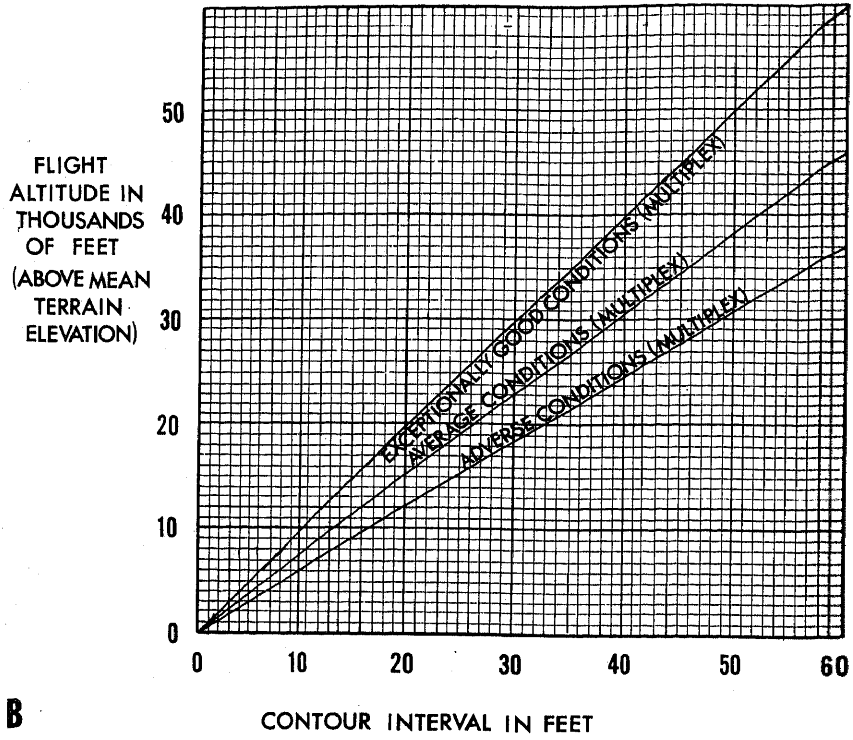
Figure 26. Plotting scale, flight altitude, and contour interval.

92. Contour Interval

The minimum contour interval that can be plotted varies between 1/500 and 1/1000 of the flight altitude (B, fig. 26), depending on the scale of the photography and the density of control. For a given scale and contour interval, the slope of the ground determines the contour spacing on the compilation. A satisfactory contour interval is one that shows the topographic features adequately, yet does not result in too closely spaced contours. The contour interval used determines not only the amount of relief information that can be shown, but also the allowable tolerances in the vertical accuracy of the map (par. 110).

93. Working Procedures

During the period of preparation for multiplex compilation the bridging and plotting operations are planned as completely as possible. The organization for bridging and plotting cannot be standardized, since this depends upon the size of the project, the nature of the terrain to be mapped, the amount and placement of control, the availability of all necessary field data, and a number of subsequently determined factors. To produce a map in the minimum time, two or three shifts are usually employed in the bridging and plotting operations. Therefore, each multiplex unit is operated by



B—Flight altitude and contour interval
Figure 26—Continued.

a two- or three-man team. The following suggestions will be found useful:

a. Have a Definite Plan. To attain the maximum efficiency and to insure the accuracy of topographic representation, it is advisable to follow a definite plan of procedure when plotting from the multiplex models, and to exercise certain precautions in each of the various steps. Generally, several operators are working at the same time on different portions of the area. The labor of coordinating and joining the work of different individuals can be reduced somewhat if each operator (or each unit when working on a shift basis) is assigned an area to plot, consisting of several adjacent pairs. However, where speed is essential, all pairs may be plotted simultaneously. A definite policy as to the interpretation of vegetation, density of detail to be shown, and the symbolization of the map features must be followed by each operator to insure uniform results which will conform to the specifications contained in the instructions for the project.

b. Keep the Plotting Sheet Clean. During the plotting from a model, the lead in the tracing pencil must be kept sharp. The proper grade of pencil and proper pressure are essential to producing a clean, thin line. The lines should be heavy enough to withstand the rubbing of the tracing table and still be visible when the plotting is completed. If a line drawn by the tracing table is too light, it should be intensified by hand. Those portions of the plotting sheet that are not actually being worked should be covered with paper.

94. Measurements in the Model

The multiplex model, when formed by properly oriented projectors, represents a portion of the earth's surface in miniature and distances are true to scale. Measurements of either horizontal or vertical distances can be made in such a model by means of the tracing table (par. 14).

a. Floating Mark. To convert the multiplex model into a conventional map, a system for measuring the model is necessary. Use is made of a "floating mark." This is a luminous dot of light on the flat, white surface of the tracing table. The floating mark is visible to both eyes through filter spectacles. When the
focused on the surface of the mod
focus of the eyes does not fuse and th
image for each eye. As the point is brought clo
the two images fuse into one, but appear to be below (or above) the surface of the model. As the motion continues, the point eventually appears to lie on the surface of the model. How closely this condition can be obtained depends on the stereoscopic acuity (depth perception) of the individual and the character of the model (sharp, clear contrasts as against flat, indefinite terrain). Directly below the floating mark is a pencil. This pencil records the orthographic projection of the floating mark, and hence any point in contact with the floating mark may be recorded in its true map or ground position.

b. Horizontal Measurement. The horizontal distance between two ground points may be obtained from the oriented stereomodel by plotting their relative positions on the manuscript with the tracing table. The distance between these points is then measured with a scale. To determine the correct ground distance, this measurement is compared with the known plotting scale, for example: $RF = \frac{MD \text{ (map distance)}}{GD \text{ (ground distance)}}$. If the known scale is 1:24, 000 and the distance between the two points is 2-mm, then: $\frac{1}{24{,}000} = \frac{2}{GD}$ or $GD = 48{,}000$-mm, and by converting to meters, $GD = 48$ meters.

c. Vertical Measurement. A vertical motion of the floating mark, obtained by raising or lowering the platen with the elevating wheel (fig. 9), can be measured by means of the height-indicating scale. When a model is properly horizontalized, elevations of points in the model may be read by setting the floating mark on the point and reading the scale. Using a conversion table (par. 51*c*), the elevations for these points can be determined.

Section II. PLANIMETRY

95. Introduction

The planimetry of a map represents the manmade and natural features in their true horizontal positions. It does not include relief, which represents the vertical positions as shown by contours. The major problem in map compilation is to make the best use of the available map space. The amount of detail to be plotted will depend upon the type of map being produced. The compiler must select the features which are the most valuable to the map user. The smaller the map scale, the more critical and difficult the problem of selection becomes. The features portrayed are generally restricted to those of a permanent nature. Whenever possible, a field classification survey will precede the compilation. During the compilation stages line weights and symbolization will conform to those prescribed under the multiplex compilation column shown in AMS TM 23a. It is imperative at all times that the plotting of all detail be accurate and legible. The hand stereoscope and contact prints should be used freely as an aid in proper identification. Where identification is doubtful, this should be noted on the plot. Planimetric features are compiled in a definite order, according to importance. In tracing planimetry, the floating mark should always be in contact with the detail in the model. Repeated reference to contact prints is necessary to distinguish obscure features.

96. Orientation Requirements

Reorienting individual models for planimetric compilation is required unless it has been possible to retain the orientation of each stereotriangulated strip while adjoining strips were being scaled. If adjusted pass points cannot be obtained, or are not desired, then planimetry of a strip can be compiled as soon as stereotriangulation is completed, without the need of resetting the models. When a model is reset for planimetry, the orientation procedures (interior, relative, and absolute) are performed in the usual way, with one permissible exception: it is not necessary that the model be absolutely leveled. Although greater tolerances might be permissible, a level solution within 1.0 millimeter across the model in both directions is quickly obtainable and affords sufficient accuracy in all cases. When contour compilation will immediately follow the compilation of planimetry, the stereocompiler should completely level the model before starting any of the compilation. The position of the model should be checked at frequent intervals throughout the compilation process. Changes in humidity cause some base sheet materials to expand or shrink appreciably, thus affecting the scale and position of the model with respect to the control base. If the model should be found out of position, either it or the base sheet must be repositioned and the features already traced checked for errors. Under extreme conditions, it may be necessary to rescale the model.

97. Order of Compilation of Features

It is preferable to compile all the features of each kind at one time; in this way the chances of overlooking and omitting any detail are minimized. A suggested procedure is to compile all main roads first, following these in order by secondary roads, buildings, obvious drainage, and woodland outlines. Railroads, shorelines, and wide streams, if they occur, should take precedence over all of these. The particular details to be compiled depend upon the type of map being prepared. A general rule to follow is to compile first those
and alinement are most important.

98. Tracing Operation

The tracing operation is simply stated: Place the floating m
upon the image of the feature to be traced; lower the pencil to the paper; slide the tracing table so as to follow the outline of the image with the floating mark (fig. 27). The floating mark may be guided through the more intricate detail by resting the edge of each hand upon the map sheet and using the fingers to move the tracing table. The height of the platen must be continuously regulated with one index finger so as to keep the floating mark always in contact with the model surface. Some suggestions with respect to tracing table operation are:

a. Each feature should be completely traced or outlined with a continuous line. Retracing a line in the opposite direction provides a good check on the accuracy of the tracing.

b. No attempt should be made to symbolize the features as they are traced with the tracing table; symbols can be added when the lines are repenciled or inked.

c. Care should be taken when plotting objects having height, such as buildings and trees, to avoid tracing their shadows instead of their true positions. High buildings in cities have to be plotted

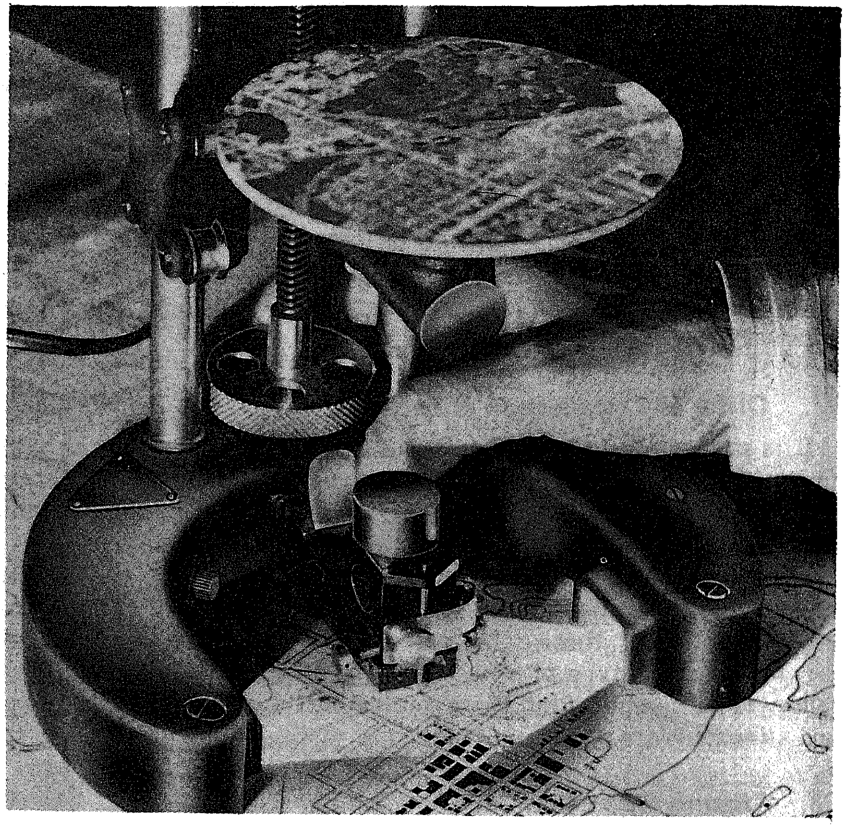


Figure 27. Multiplex compilation.

by their roof lines, as the photograph perspective may cause their bases to be partially obscured. It is important to have the floating mark in contact with the feature being traced, at the correct elevation.

99. Reference to Contact Prints and Supplementary Source Materials

It will be necessary when compiling the smaller and more obscure details of planimetry, such as dense collections of buildings, railroad yards, trails, and streams in heavily wooded areas, to refer repeatedly to the contact prints and supplementary source materials as an aid in identifying features contained within the multiplex model. The brilliance and clarity of the photographs as seen through a simple lens stereoscope far surpass that of a multiplex model and many details can be seen that might be overlooked if the multiplex models were used alone. When details have been identified by use of the prints, they usually can be interpreted well enough in the multiplex model to be plotted accurately.

Section III. CONTOURS

100. Classification

Contour lines are the principal means used to show the shape and elevation of the land surface. Each contour line on the map represents a definite ground elevation measured from mean sea level, and the contour interval is the difference in elevation between adjacent contours. Contours are continuous lines connecting points of equal elevation. To make maps more readable, contours are classified into three categories—index, intermediate, and supplementary—and distinguished from each other by different line weights. The index contours, usually every fifth contour, depending on the basic interval, are accentuated by making the line heavier than the intermediates. Supplementary contours, used in the flatter areas of some maps, are shown as dashed lines. Spot elevations should be added in critical areas to clarify the relief features which are not clearly identified by the contours. The amount of detail shown varies inversely with the map scale; some of the relief detail mapped at the scale at 1:25,000 may be omitted at the scale of 1:50,000. The compiler should always strive for good topographic expression; that is, the typical characteristics of the ground surface are clearly represented. Good topographic expression makes the map easier to read, and the relief features more easily comprehended. In tracing contours, the platen is clamped at the height of the chosen contour and the tracing table is guided so as to keep the floating mark always in contact with the ground. Before contours are traced, minor drainage is drawn in pencil to serve as a guide in alining the contours.

101. Visual Skill Required

Skill in contouring comes only after weeks of practice and even then not to everyone. A special kind of visual ability is required, which, if lacking in the beginning, may prove impossible to develop. Multiplex trainees, therefore, should be selected only after a test of their stereoacuity (app. IV). This test should not only measure their ability to perceive the depth difference between two points in space, but also their ability to perceive the shapes of larger masses, as demonstrated by their ability to trace a reasonably correct contour line. When making any stereoscopic measurement with a floating mark, but most especially when contouring, the observer must strive for an awareness of the model around, above, and below the mark itself. Staring at the floating mark will obstruct this awareness and is a habit which beginners must avoid.

102. Orientation Requirements

Contouring requires that the model be both positioned and leveled as accurately as possible. Even though all models of the strip remain in orientation, the leveling of more than one model at a time is impractical and makes it compulsory to compile contours model by model, leveling each model in turn. During the compilation of contours, the stereocompiler should frequently check both the position and the level of the model. He should even more frequently check the consistency of his elevation reading on a given point (index reading), as his personal "index" may be subject to a variation of 0.1 to 0.3 millimeter. Nearly all observers experience this "change in index" at one time or another. When it does occur, it usually takes place during the first minutes of stereoscopic observation. As a person's stereoscopic experience increases, this tendency of his "index" to change diminishes. Before plotting the contours, the horizontalization of the model should be checked and spot elevations at various prominent road intersections and hilltops should be read and recorded. The illumination of both projectors should be adjusted until they are equal.

103. Contour Tracing

After orientation of the model has been completed and the index reading checked, the model is ready to be contoured. The platen is set and clamped at the height of any suitable contour and the contour is traced as a continuous line by guiding the floating mark wherever it must go to keep it always "on the ground." It is best to begin either at the top or at the bottom of a slope rather than at random in between. The terrain is carefully studied to assure that [illegible]gical, fit the terrain, and conform to the [illegible]s and known vertical control. Depending upon the character of the topography, it is usually preferable to compile by features, or by small groups of features, rather than threading one contour across a whole model before starting to trace the next contour. In models of low relief, best results will be obtained by following the drainage pattern and tracing the contour several times, accepting the most logical one, and erasing the others from the sheet. It is not advisable to skip contours and fill in later. Generally, drawing successive contours will more faithfully represent the terrain. When one contour line has been completed, the platen is raised or lowered an amount equal to the contour interval and another line is traced. In this manner, contours are compiled over the whole model. In steep terrain, it is often unnecessary to trace every contour from the model. Every other contour, or in some cases every fourth or fifth contour, will be sufficient. The intermediate contours can be sketched in afterwards, when the whole compilation is shaped or retouched, to give the proper "expression" to the lines. Contour expression refers to the spacing of contours to illustrate the actual ground conditions. Slight variations in contour tracing create unequal slopes on hillsides, ridges, and drain crossings. A small displacement of one or two traced lines can improve the portrayal without affecting the contour accuracy. Changing the accentuation of a rounded trace to a sharp V, or vice versa, in a drain crossing shows the true topographic picture. The actual movement of the contour line is seldom more than the width of a line to attain the desired result.

104. Contouring Difficult Areas

Difficulty in contouring is often experienced in areas of relatively flat terrain, in densely wooded areas, in areas covered by shadow, and in areas that offer either too much or too little image contrast. Ordinarily, it will not be necessary for the stereocompiler to leave these areas uncompleted if he makes good use of the contact prints and if he applies knowledge of topography.

a. Flat Terrain. In contouring flat terrain, when the average slope of the ground becomes too small, say, less than one meter in a hundred, the horizontal position of a contour line and hence its shape becomes difficult to determine. Rather than trace a contour as a continuous line, the stereocompiler may find it necessary in this case to move the floating mark at right angles to the general direction of the contour in an attempt to determine a band within which no separation between the mark and the ground can be noticed. After a number of bands have been located, each contour line can be sketched in the most logical position within its own band.

b. Wooded Areas. When the ground is completely obscured by trees, accurate contours cannot be traced. Whenever possible, therefore, aerial photography is taken when leaves are not on the trees, so that no difficulty is ordinarily experienced in seeing the ground except in areas of evergreen growth. When evergreens or leafed-out trees hide the ground surface, contouring is possible provided small portions of the ground can be seen through openings in the trees. If these openings are numerous enough, reasonably accurate contours can be drawn from one opening to the next by carrying the floating mark at a uniform distance below the tops of the trees. In places where the tree heights would logically be expected to be greater or less than average, an estimated allowance must be made for the difference in their height.

c. Shadows. Large areas in shadows cannot be contoured when detail cannot be seen in the shadow. Contours can be run through small shadows, however, with little difficulty if the stereocompiler does not let himself be deceived into mistaking the impression of relief naturally associated with shadows for a true stereoscopic impression. An example of this deception can be seen in spotty shadows of partly leafed-out trees, which often give the impression that the ground has a very uneven surface although in reality it may be quite smooth.

d. Insufficient Contrast. Unbroken fields of grass or stretches of sand or snow often present such a monotone that it is impossible to make a stereoscopic reading upon them. If such areas are not too large, contours can be sketched across them with the aid of the contact prints.

e. Excessive Contrast. It is a natural tendency for white or very bright images to appear slightly higher or nearer to the eye than dark-toned images. This can be demonstrated if a single photograph is printed on two diapositives, being offset on one so that a stereoscopic model of the pair may be set up. Although this model has no relief, being formed by two identical images, there is a strong tendency to see alternate light and dark areas as an uneven surface. The stereocompiler should bear this phenomenon in mind when reading control elevation as well as when contouring.

105. Drainage

Regardless of the skill with which the floating mark is used in tracing contour lines, some smoothing, respacing, or reshaping of the lines will be necessary if they are to express the characteristic features of the terrain with utmost clarity and proper emphasis. As most land forms have taken shape to some extent through the
of drainage is of great impor-
proper expression of these forms. Drafting
[illegible] expression into a multiplex compilation will always be
all the drainage, large and small, is lightly drawn in with the tracing table prior to the final inking or repenciling of the contours. Then, when the stereocompiler is repenciling or inking the contours, the drainage lines help him to aline the contours precisely and to shape them with the proper expression. Reshaping contours to fit the drainage pattern results in a more accurate map than changing drainage to fit contours.

106. Spot Elevations

Spot elevations are approximately correct elevations of certain topographic and cultural features shown in order to furnish map users with more specific elevations of these features than may be interpolated from the contours. Spot elevations are determined and compiled on the base manuscript for such objects as road forks, summits of mountains, and prominent hills; water surfaces of lakes, ponds, and wide rivers; stream forks; prominent high points in roads; bottom elevation in depressions; large flat areas; and section corners, boundary markers, and other well-defined points. Spot elevations may be recorded wherever needed to supplement the contouring, but ordinarily should not be shown on steep slopes. The recording of such spot elevations is an integral part of multiplex compilation. Each elevation is determined by averaging repeated readings in the multiplex model. All elevations determined by reading in the stereomodels must be preceded by the letter T when shown on the manuscript, thus: T678. When map location of a spot is in doubt, the point is indicated on the map sheet by a small right angle cross.

107. Compilation of Extensions

a. When necessary to bridge control, or when several successive models in a strip are assigned to an operator, the diapositives covering the area should all be set up in the multiplex projectors. By bridging methods, the scales of these models are adjusted to fit the horizontal control. If
of the control points of the s
sible to adjust the bridge so
points are read, but the error
tions are not close enough to
nor can the desired contour a
entation, it is usually desirable to draw the plan
complete strip before horizontalizing each model independently for contouring. It is best to average the vertical adjustment of the strip to fit all the vertical control as closely as possible. The positions may then be plotted throughout the adjusted strip without appreciable error. This procedure is used only when the end product is to be a small scale map.

b. As a check on the adjustment of models, pass points between models should be located near the edges of the strip, as well as at the center. When the elevation of the center pass point is adjusted to read the same in both models, the elevations of the side pass points are seldom the same. In the usual case, there is a tilt between the datums of the two models with the two datums intersecting at the center of the model. This is known as "cross tilt." It indicates that there are errors in relative orientation remaining between the projectors of one or both models. When large cross tilts appear, a closer adjustment of the models should be attempted so the cross tilt will be reduced to a small amount, not more than 0.5 mm at the edges of the models. With models adjusted to that refinement, there will be no measurable position error in a short bridge (five or six models).

c. When the scale and orientation of the strip have been established, it is best to immediately plot several reference positions from the strip to serve as check positions later on. The crosses indicating the principal points on the diapositives are good marks to plot and serve other purposes as well. They are plotted by setting the tracing table to the elevation of the model at the cross. At the same time, features around all sides of the strip should be plotted where other strips will join later. These will serve to indicate how the strips are tying together and help in their adjustment. The planimetry normally plotted does not always contain sufficient detail to permit a proper tie between strips. For this reason, additional features such as fence and field lines, small trails, and sharply defined woods and drainage lines should be plotted. Where nothing better exists, trees may be plotted. Following the plotting of the principal point crosses and a skeleton of the planimetry, the complete planimetry of the strip should be plotted.

d. A model at one end of the strip is next horizontalized, the plotting sheet is reoriented to the planimetry already plotted, and the contours are plotted for that model. Other models of the strip are then horizontalized and contoured in succession.

e. When it is necessary for an operator to join his work with plotting already completed, it is essential that he transfer the detail from the edges of the other sheets to his sheet to insure proper matching. The work should be planned to keep edge transfers to a minimum. Edge transfers are made far enough ahead of actual need so no delay in the plotting will result.

CHAPTER 8
ACCURACY EVALUATION

Section I. INTRODUCTION

108. Specifications

Accuracy specifications are required in modern topographic mapping so that all maps of each series will be of a uniform accuracy; map users will know the accuracy that can be expected; and map revision can be accomplished economically and expeditiously. Specifications that established, in a general way, the accuracy of a topographic map were used in the United States as early as 1910. Since then, accuracy specifications have been used on all types of mapping projects, including city plans, highway route location, etc. The National Standards of Map Accuracy were established in 1941 and they define the accuracy specifications for standard
planimetric and topographi
met with the proper applica
ever, the mechanical and o
the accuracy which can be
accuracy of the multiplex
graphic materials; the base-
terrain, control, and photograp
operator. Some of these factors are rather
vary so greatly that they can only be estimated for
project. In the following sections, each factor is discussed
net result under ordinary conditions is estimated.

109. Horizontal Accuracy

The established standard for horizontal accuracy for maps requires that 90 percent of all well-defined cultural and planimetric features shall be shown within $\frac{1}{50}$ of an inch, at publication scale, of their geographic positions as referred to the map projection. For example, on a 1:50,000 scale map, 90 percent of all well-defined features must be horizontally accurate to within $83\frac{1}{3}$ feet. To produce a map that will comply with the horizontal tolerances, it is necessary that all the preliminary operations in the preparation of the map be planned with the accuracy requirements in view.

110. Vertical Accuracy

In multiplex mapping, the intersection angles of corresponding rays are such that vertical locations are less definite than horizontal locations. For this reason, the vertical error is more critical; and in a single model, if the vertical accuracy is obtained, the horizontal accuracy presents no problem. When the ground survey control is such that multiplex triangulation is necessary, the horizontal accuracy in triangulated positions must be considered. Vertical accuracy standards, as applied to contour maps, shall require that not more than 10 percent of the elevations shall be in error by more than one-half the contour interval. Spot elevations shall be within one-fourth the contour interval. For example, on a 1:50,000 scale map with a 20-foot contour interval, 90 percent of the contour lines must be vertically accurate to within 10 feet (in contrast to an allowable 5-foot spot elevation error).

111. Unit of Measurement

A multiplex model is a reconstitution, to scale, of a portion of the earth's surface. The accuracy of this scaled model can best be discussed in terms of measurements in the model; these measurements are made in millimeters. All measurements in the model can then be converted to ground distances by reference to the scale of the model (par. 94).

112. Altitude and Projection Distance

In the model, the projection distance duplicates, to scale, the flight altitude at which the photographs were made. As the projection distance is reasonably constant in all models, it comprises a convenient common reference for ground and model accuracy. A model error is a certain fraction of the projection distance and is therefore the same fraction of the flight altitude expressed in [illegible]. Thus, the normal projection dis- [illegible] mm, a model error of 1-mm is $1/360$ of the projection distance and represents a ground distance error of $1/360$ of the flight altitude (app. II).

113. Selection of Flight Altitude

The maximum flight altitude which will provide the required accuracy is most economical. If the model accuracy can be estimated, the maximum flight altitude to obtain the required vertical accuracy can be determined by simple proportion. For example, when the ground elevations are to be determined from a model with an accuracy of $1/600$ of the flight altitude and the allowable error in any elevation is 20 feet, the maximum flight altitude is determined as follows: $1/600 = 20/\text{altitude}$; altitude $= 20 \times 600 =$ 12,000 feet.

114. Base-Height Ratio

Given equal conditions, an increase in the ratio of the air base to the flight altitude decreases the error in measuring elevation in the model, increases the accuracy of relative orientation, reduces the deformation in the model, and makes stereoscopic perception stronger. With any particular camera-printer-projector combination, photography with 50 percent overlap should give twice the vertical accuracy of photography with 75 percent overlap. This increase in accuracy applies directly only when other conditions are equal, as the base-height ratio is only one of many factors affecting the accuracy.

Section II. PHOTOGRAPHIC EQUIPMENT

115. Camera

a. The precision of the aerial camera is controlled by specifications that require the camera optical system meet certain minimum requirements. The focal plane must be set so that the calibrated focal length shall be 153-mm ± 3.0-mm. The camera shall function properly at the altitude specified and shall expose a 9 x 9 inch negative. The lens, focal plane, and fiducial marks must be permanently fixed in rigid orientation with one another. The coincidence of the optical axis and the perpendicular from the rear node of the lens to the film plane shall be such that no asymmetry is indicated by the resolving power at the four edges of the film area. Straight fiducial marks located at the centers of the 9 inch sides shall indicate the position of the perpendicular from the rear node of the lens to the film plane to within 0.002 inch. Lines connecting opposite pairs of fiducial marks shall intersect at 90°, ± 1 minute of arc. The overall focal plane surface of the platen of the camera shall be flat, under operating conditions, to within ± 0.0005 inch. The film shall be held flat in the focal plane, at the instant of exposure, to within ± 0.0005 inch.

b. Aerial cameras used in conjunction with the multiplex equipment are the T–11 and KC–1. The T–11 is equipped with the 6-inch metrogon lens. Specifications for the metrogon lens require that the optical distortion in any part of the field of the lens shall not exceed 0.13 mm or be less than 0.10 mm at those angles from the optical axis where the largest amount of displacement of the image from its distortion-free position occurs. These displacements refer to the distances computed using the calibrated focal length. The KC–1 mapping camera is equipped with the planigon lens. Since specifications for the planigon lens limit the lens distortion to ± .010 mm from zero distortion, the lens is considered "distortion free." Thus, the KC–1 camera is capable of producing mapping photography without any significant distortion.

c. The metrogon lens distortion and the focal length variations are compensated for in the reduction printer. The mechanics of the aerial camera normally do not contribute any significant errors in the photography. The most frequent source of error is that resulting from the lack of film flatness at the time of exposure. This condition may result from either a malfunction of the vacuum system or from a deviation of the film platen from a true plane. In cases of vacuum system failure, very large errors in both the x and y parallax solutions usually would be apparent in the multiplex stereoscopic model; however, if the error existed in the film platen, the errors would probably be of much smaller nature and apparent only in the final accuracy of the completed model. Any vertical deviation from a true plane would result in a horizontal image displacement on the exposed film, similar to that which is caused by radial lens distortion. The exact vertical model deformation would depend upon the location and magnitude of the platen error.

116. Lens Distortion Compensation With the Reduction Printer

The two major lenses in use in the United States for obtaining mapping photography are the metrogon and the newer planigon lenses. Since the planigon lens is considered free of distortion for the purpose of multiplex mapping, the reduction printer used for planigon photography does not include compensation optics. The metrogon lens, however, creates a comparatively large distortion in the exposure and a means is provided in the reduction printer to compensate for this displacement. Perfect compensation can only be obtained when the characteristics of the camera lens and the printer optics are exactly equal and opposite. Since the deviation of the metrogon lenses from the nominal has the same general value as the deviation of the planigon from zero distortion (par. 115), the resulting errors in parallax measurement can be considered comparable when using either metrogon or planigon lenses in conjunction with multiplex equipment. Since the distortion characteristics of the individual printer would introduce small additional errors, the resultant distortion in the diapositive (fig. 5) could have a magnitude of approximately .024 millimeters. The exact vertical model deformation resulting from this residual distortion would depend upon the shape and magnitude of the curve.

117. Accuracy of Photographic Materials

a. Cartographic Film. The standard aerial film designed specifically for cartographic purposes is: *Film, Photographic, Type 1A, Class A.* All aerial films are classified as either Type 1A or Type 1B. Type 1A film is aerial camera film with an emulsion coating on a special base having a high degree of dimensional stability. Type 1B film is aerial film acceptable for reconnaissance photography, but not satisfactory for cartographic work. There are three classes of film: Class A, Class N, and Class K–1. Class A film is panchromatic (sensitive to light of all colors), and has an exposure index of 80. Class N film is also panchromatic with a speed (exposure index) of 200. Class K–1 is infrared film with a speed of 150. The high speed of Class N and the infrared sensitivity of Class K–1 are not usually necessary in cartographic photography. The most important property of a cartographic film is its dimensional stability. It is essential that little or no change occur in the dimensions of the negative from the time at which the exposure is made until such time as the negative is used cartographically. Three types of dimensional changes may occur in the negative during any stage of its use: a uniform change in the length of the film; a uniform change in the width of the film; or isolated changes in dimensions in small areas (local area distortions) which are extremely small and usually may be disregarded as negligible. If the uniform changes in length and breadth are the same, they constitute only a small change in scale which can be compensated for by adjustments of the calibrated focal length. When the dimensional changes in length and breadth are essentially different, the result is *differential distortion* which is more difficult to correct. Cartographic film should have a minimum of local area distortion, little or no differential distortion, and only a small change in scale. Dimensional changes are brought about principally by changes in relative humidity and temperature, processing of the film including drying, and aging of the film. To minimize the possibilities of such changes, the negative should be developed and printed under conditions of relative humidity and temperature approximating as closely as possible those encountered during the exposure of the film. During processing a small amount of shrinkage is bound to occur. This will be kept to a minimum by careful control of the amount of heat and tension applied during the processing, especially during drying. Uniform shrinkage of aerial film has the effect of varying the camera focal length. If deemed necessary, this can be compensated for by correcting the reduction ratio of the reduction printer accordingly. Local area distortion is undesirable, but may be present in insignificant amounts in good cartographic film. Care in processing, handling, and storing negatives is essential. When properly handled, cartographic film will not cause noticeable errors in the projection. Current specifications on mapping film permit the following approximate dimensional characteristics when the film is processed and handled under normal conditions.

(1) *Effect of humidity.* A 50 percent change in humidity will result in a relative humidity change of 0.045 inch per 9 inches of film, with 0.0045 inch differential shrink-

age between the 9 inch length and width dimensions of the film.

(2) *Effect of processing.* As a result of processing, the film base will shrink a nominal 0.009 inch per 9 inches of film, with 0.0027 inch differential shrinkage between 9 inch length and width dimensions of the film.

(3) *Effect of storage.* When the processed film is stored under given temperature and humidity conditions, it continues to shrink with age. It must be processed and dried at proper temperature and drying rates to keep the film from having much larger and more unpredictable dimensional changes. Constant vigilance over processing and drying techniques is necessary to minimize their effects.

b. Diapositives. Diapositive plates are of specially selected glass flat enough to eliminate measurable errors in the model. However, plates that "rock" or make poor contact with the diapositive cradle should be discarded. The most probable source of diapositive error is that due to processing. Touching or rubbing the wet emulsion warps the image. A small local distortion (for example, 0.01 mm) may easily cause a 0.1-mm error in the model due to the change of scale in projection. Another error may be caused by improper alinement of the negative in the reduction printer. A small error may be tolerated if it is the same in all diapositives. The film roll should be passed through the printer in one direction only, and the alinement should be accurate to ± 0.1 mm in the negative plane. Careless alinement of the negative, especially for terrain of great relief, may cause large errors in the model. Present specifications [illegible] them to be flat within 0.0007 inch per inch. It is reasonable to expect that the photographic materials alone (film and glass plates) can introduce a mean error in parallax measurement on the order of 0.015 mm in a model. Under carefully controlled conditions, it is estimated that the mean error from this source will not exceed 0.010 mm.

118. Effects of Instrument Errors

Since the fundamental operation in the measurement of heights and contouring in any stereophotogrammetric process resolves into a measurement of the stereoscopic parallax of each of a multiplicity of points within a stereoscopic model, the most convenient basis for an evaluation and comparison of the probable effect of various sources of error in each piece of equipment is to determine the effect of each on the accuracy of measurement of stereoscopic parallax at the scale of the photography. In the simple case where the photographs are truly vertical at equal altitudes above level terrain, the ratio of elevation error to flight altitude above terrain is equal to the ratio of parallax measurement error to the air base at the scale of the photography, or

$$\frac{dh}{H} = \frac{dp}{b}$$

where dh = error in elevation
dp = error in parallax measurement
H = flight altitude
b = air base at scale of photograph

In order to compile at a C-factor of $1/1000$, it is necessary that at least 90 percent of the time the accuracy of measurement be such that the ratio of error in height interpolated from compiled contours to the flight altitude is $1/2000$ or less. Thus, for 9 by 9 inch 6 inch focal length photography, with the air base at the scale of the photographs equal to 100-mm, the parallax measurement must be made within $1/2000$ of 100-mm or 0.05-mm 90 percent of the time. To obtain this accuracy, the average error in stereoscopic parallax measurement must be no greater than about one-half the tolerable error for 90 percent of the measurements. In the case cited, the average error must not exceed about 0.025-mm.

119. Calibration and Adjustment

Errors resulting from laxity in calibration or adjustment of the photogrammetric equipment can be of a most serious nature. In the multiplex plotting equipment the most frequent sources of error are the projection lenses and the reference table. The projection lenses may cause residual errors in the completed compilation through lens distortions, while the multiplex table errors are transmitted directly to the model through vertical deviations of the table from a true plane. Present specifications require that the vertical model deformations in the stereoscopic model, due to the optics of the projector pairs, will not exceed ± .15-mm from a true plane. The multiplex table or plotting surface is also required by specifications to be a true plane within a tolerance of ± 0.05-mm over the entire surface, and is further required not to deviate from the plane by more than ± 0.025-mm in any one square foot area on the table surface.

120. Projectors

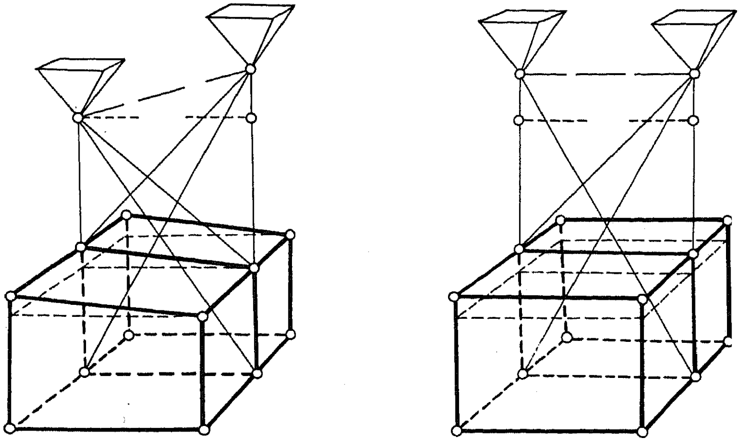
When the projectors are properly oriented, they are designed to project identical grid diapositives to form a stereoscopic model that is flat within ± 0.15-mm. The principal distance of each projector is 28.182-mm within ± 0.1 percent. The distance from the node of the lens to the appropriate surface of the diapositive is true as marked, within ± 0.02-mm. Any error existing in the flatness of the diapositive surface causes no measurable error. The combined error in the projector will cause errors less than ± 0.15-mm in the model.

121. Interior Orientation

Figure 28 shows the deformations of a model caused by small errors of principal distance and principal-point location. Principal distance and principal-point errors have no effect upon a model that is a flat surface, but their effects increase in proportion to the relief of the model. Only the vertical effects are important, the horizontal displacements are seldom large enough to be significant. In figure 28, the dashed lines indicate the normal shape of a model which, in this illustration, is assumed to be a block with rectangular faces. The solid lines then picture the nature of each particular deformation. The magnitudes of the deformations shown are greatly exaggerated in proportion to those that would occur in practice. Both principal distance error and principal-point error can result from improper calibration of the aerial camera, reduction printer, or multiplex projector. Principal-point error can also result from a failure on the part of the diapositive maker to aline each negative properly in the printer, or from a failure on the part of the multiplex operator to center each diapositive correctly in its projector. Those errors having their source in the optical or mechanical performance of the camera or diapositive printer are very likely to be duplicated in each projection. The errors of negligent operation are more likely to occur in one projection only.

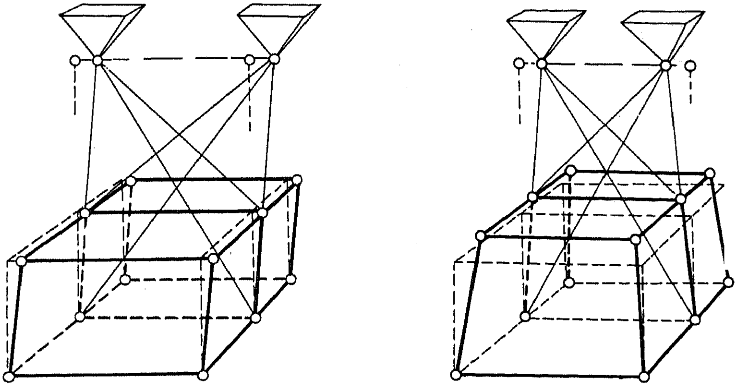
essential effect of principal distance
ale of the model with respect to the horizontal scale of the model. An error in the principal distance of any projector bears the same proportion to the average principal distance as the resultant error in the vertical dimension of the edge of the model under the opposite projector bears to the average height of the model. Thus when both principal distances are equally in error, the vertical dimension of the whole block is uniformly in error; if the principal distance error is, say, 1-mm in a principal distance of 30-mm, the vertical error would amount to 1 foot in 30 feet, 10 feet in 300 feet, and so on.

b. Principal Points. When the principal points are displaced so as to have unequal x components, errors of vertical scale occur. In this case, the vertical scale is uniformly affected over the entire model. When both principal points are displaced equally in any direction, a condition is obtained wherein there is no scale error and no y parallax error. When the principal points are displaced so as to have unequal y components, y parallax will be evident in the model at all elevations above and below the plane of the



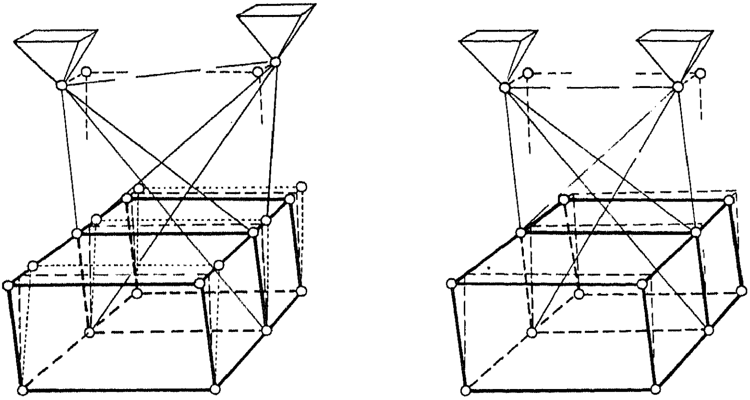
PRINCIPAL DISTANCE - ONE ONLY

PRINCIPAL DISTANCE-BOTH EQ



PRINCIPAL POINT - EQUAL IN X

PRINCIPAL POINT - OPPOSITE IN X



PRINCIPAL POINT - OPPOSITE IN Y

PRINCIPAL POINT - EQUAL IN Y

Figure 28. Effects of interior orientation errors.

points used for clearing the y parallax in the relative orientation procedure.

122. Relative Orientation

The effects on the model datum of a small error in the setting of each motion of the projector are pictured in figure 29. These effects, as indicated by the differences between the dashed and solid outlines, are greatly exaggerated for illustrative purposes. Assuming a maximum residual y parallax of 0.1-mm, the magnitude of any effect is but a few tenths of a millimeter, excepting of course, the effect of x motion which involves no y parallax. These errors affect elevations in the model more seriously than they do horizontal positions. The horizontal deformation resulting from a residual y parallax of 0.1 or 0.2-mm is not significant in a single model. As indicated in figure 29, errors of relative orientation affect the vertical datum of the model essentially as follows:

a. Y Motion. The error has no effect upon the model datum.

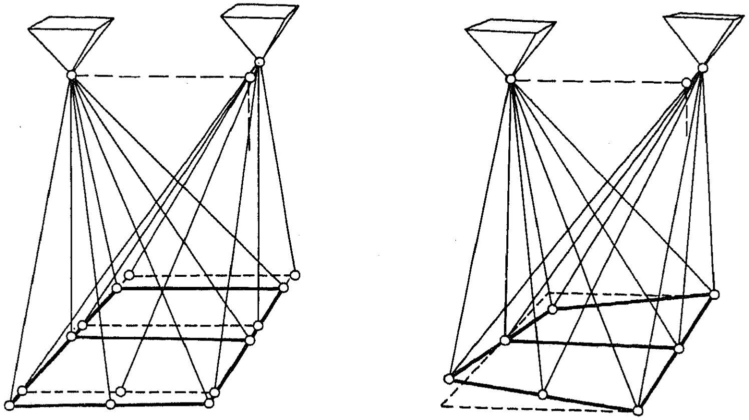
b. X Motion. The effect of this error is to change the scale of the model. The uniform raising or lowering of the model datum with respect to the table top, or instrument datum, is offset by re-indexing the scale of the tracing table.

c. Z Motion. The principal effect of this error is to tilt the model datum about a y axis. As the datum remains flat, this effect is offset by the subsequent leveling of the model when absolute orientation is performed. The maximum tilt of the model permitted by 0.1-mm y parallax in the model is 0.2-mm.

d. X Tilt. The principal effect of error from x tilt is to produce [illegible] the model datum. The maximum [illegible] occurs along the diagonals of the model. In the x and in the y directions, the datum remains uncurved; that is, an xz or yz section is a straight line. Maximum warp permitted by 0.1-mm y parallax in the model is 0.8-mm.

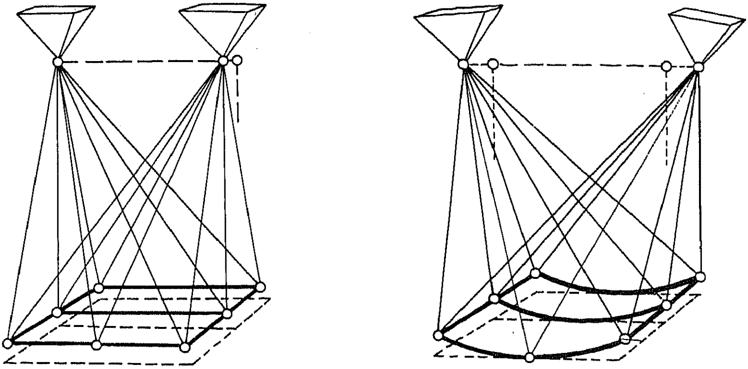
e. Y Tilt. The principal effect of error from y tilt is to produce a cylindrical warping of the model datum. The maximum curvature of the datum occurs in the x direction. The datum remains uncurved in the y direction. Convergent y tilt lowers the y direction centerline of the model with respect to the left and right edges, as shown in figure 29; divergent y tilt causes this centerline of the model to be raised. Maximum warp permitted by 0.1-mm y parallax in the model is 0.1 mm.

f. Swing. The principal effect of this error is to tilt the model datum about an x axis. As the datum remains flat, this effect is offset by the subsequent leveling of the model when absolute orientation is performed. Maximum tilt permitted by 0.1-mm y parallax in the model is 0.44-mm.



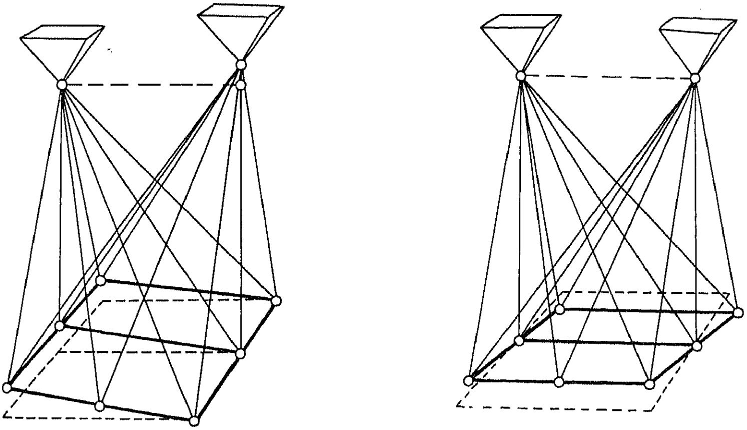
Y-MOTION

X-TILT



X-MOTION

Y-TILT



Z-MOTION

SWING

Figure 29. Effects of relative orientation errors.

g. Summary. To summarize, it is seen that of the errors only two, namely, *x* tilt and *y* tilt, have a significant effect. Each of these warps the model datum in characteristic manner, by which the error may be identified. It is also noted that no relative orientation error permits any curvature of the model datum in the *y* direction. Error of relative orientation can result not only from failure of the multiplex operator to clear *y* parallax completely, but also from photographic distortion. As the *y* components of distortion at each of the four corner locations where *y* parallax is observed usually differ between the two photographs of the overlapping pair, erroneous projector settings will undoubtedly result from clearing *y* parallax completely at these positions. Fortunately, however, the effect of distortion in present-day multiplex projector-printer-camera systems is not appreciable in a single model. As relative orientation is but a means to an end, the ultimate objective of all orientation processes being absolute orientation, it is permissible to use the flatness of the model datum instead of *y* parallax as a means of adjusting the *x* tilt and the *y* tilt setting. In fact, the ultimate setting of these two motions must depend on their effect on model flatness as revealed during the course of leveling. The *x* tilt motion especially creates a warp of the model datum more critical than its *y* parallax effect.

123. Character of the Terrain

[illegible] greatly affected by the character [illegible] onsiderations apply.

[illegible] tereoscopic perception is directly [illegible] image viewed. It would be impossible to form a stereoscopic model, or to make measurements, if absolutely no contrast existed in the diapositives. Fortunately, natural conditions and modern photography have helped greatly, but there are many areas where the problem still has to be solved. These areas are of two classes: too little, and too much contrast. Flat grasslands, alkali flats, barren beaches, and river bottoms have too little contrast (par. 104*a*). Bordering detail helps orientation, but measurement is always difficult. High-altitude photographs of wooded areas with a large percentage of clearings have too much contrast. It is then difficult to retain the photographic detail in the light areas without destroying it in the darker areas. Diapositive contrasts and projector illumination can be controlled to help solve this problem.

b. Woods. Dense woods obscure the terrain. There are three partial solutions when contouring. If numerous clearings are available, a combination of logical and continuous contouring can be used. Extremely dense woods offer the possibility of measuring the mean height of the trees, applying a correction, and contouring on top of the woods (par. 104*b*). In some situations, photography can be planned when the trees are leafless.

c. Water. It is impossible to obtain stereoscopic models of water areas. This, in effect, reduces the working area in a model and in turn reduces accuracy. The position of great water areas must be considered in planning the flight-line pattern.

d. Relief. Great relief normally offers no special problem as long as the ratio of differences in ground elevations to flight altitude is less than the ratio of usable projection distance to total projection distance. Special cases arise where steep slopes are masked, in which cases special flight lines may be necessary. A combination of great relief and large tilts causes certain types of error to affect the model; however, the resulting errors are small.

e. Flat Areas. When the total amount of relief in a model is within or near the probable accuracy of the mapping, the resulting contours are difficult to draw and may be displaced considerably. In the production of military maps, this is not of critical importance, since the required vertical accuracy can still be held. Maps for some engineering purposes require a more accurate determination of the contour positions.

124. Character of Control

A multiplex model can be no more accurate than the fixed ground control to which it is scaled and horizontalized.

a. Horizontal Control. The amount of horizontal control used depends upon the general situation. The greater the density of this ground control, the greater will be the horizontal accuracy of the map. Where existing ground control must be used, the accuracy of the map will depend upon the density of this control, the accuracy of its location, and the accuracy with which it can be identified. If the situation is such that the control network can be planned, advantage should be taken of the multiplex equipment in bridging and only enough control established to be consistent with the scale and accuracy of the final published map. When using existing horizontal control, or establishing new control, the following considerations are applicable:

(1) Identification of existing control points on aerial photographs presents difficulties. Errors in identification affect the resulting accuracy of the map.

(2) If control data are very old, the positions are often difficult to find in the photographs. However, fairly satisfactory multiplex bridges have been made by use of field established control points pricked on aerial photographs

from old descriptions, without recovering the stations by ground reconnaissance. Such a procedure is not recommended except when it is impossible to recover the stations.

(3) When ground control has been established and descriptions are available, the points should be pricked and marked on the photographs.

(4) When establishing new horizontal control, points that will be readily identifiable in the multiplex model are preferred. Points best suited to this purpose are the right angle intersections of cultural detail, such as roads, fences, field corners, and ditch lines. Small isolated trees may be used where none of the above is available. Care should be exercised in selecting the horizontal control points, so that changes in the appearance of the terrain during the interval between the field work and the photography will not lead to misidentification. Classification surveys and the recovery of ground control are fully discussed in TM 5–234.

b. Vertical Control. To obtain the best horizontalization of each multiplex model, vertical ground control points near each corner of each model should be available. When controlling elevations are established by multiplex extensions or bridges, the accuracy of the map will decrease. The accuracy of establishing vertical control by multiplex extensions and bridges is discussed in paragraphs 67 through 72, 79, 82, and 83. The accuracy of the map [illegible] of the vertical control used. [illegible] ly important that the vertical control [illegible] accuracy consistent with the contour interval. Vertical control points with errors no greater than one-tenth of the contour interval are sufficient to avoid error in the map due to this cause. Before using existing vertical control points, an inspection should be made to determine: whether the elevation of the point has changed since the control was established; that the point can be positively identified on the aerial photographs; and that the ground surrounding the point is approximately level. When there is any doubt of the accuracy of an elevation, the use of that point should be rejected. When using existing vertical control, or establishing new control, the following considerations are applicable:

(1) Vertical control points must be identifiable in the multiplex model.

(2) A point surrounded by level ground will give the correct measurement in the model even though the exact horizontal position of the point cannot be identified.

(3) Points on sloping ground are satisfactory for use as vertical control points, provided their horizontal position is accurately identified.

(4) Points that lie close to abrupt changes in elevation, such as near a cliff, should be avoided.

125. Characteristics of Photography

The characteristics of aerial photography directly affecting the accuracy of multiplex mapping are described below.

a. Flight Lines. Crooked flight lines in themselves cause no error in the individual model, but they result in *crab* and make multiplex triangulation more difficult.

b. Crab. Crab reduces the size of a stereoscopic model, which in turn makes parallax removal and horizontalization more difficult.

c. Overlap. Excessive overlap (over 60 percent) reduces the base-altitude ratio. Insufficient overlap (less than 55 percent) makes control or pass point selection difficult.

d. Tilt. The multiplex equipment allows the use of tilted photographs, but excessive tilt may cause improper side lap or forward lap. A large amount of tilt in photographs of terrain having great relief may introduce noticeable errors in the compilation.

e. Exposure and Development. Improperly exposed or developed film results in loss of detail. This loss limits the ability of the operator to make interpretations, to attain accurate orientation, and to make accurate measurements in the model. Good photographic contrast aids the accuracy of measurement of elevations in the multiplex model.

Section III. CONTROLLING ERRORS

126. Introduction

The goal of many experiments has been the exact recovery, to a reduced scale, of the camera position and orientation for each exposure. No scheme has yet been adequately successful. Various methods have been unsuccessively tried for measuring the tip and tilt in the camera at the instant of exposure. Efforts to measure the height of the airplane above an identifiable terrain point have also been unsuccessful. The ultimate in mapping photography is to have all photographs of a strip exposed at a constant flight altitude. This is done within the limits of the pilot's ability and the accuracy of the plane's altimeter. By starting with the assumption that the altitude in a particular strip is constant, it is possible to neutralize, or to adjust to a certain extent, the errors introduced by the false tip and resulting BZ errors. One method is to set all the projectors at the same height and make minor changes in BZ; usually such a change will remove some of the parallax from the models without causing the projectors to deviate greatly from the mean height. Perfect stereoscopic models are not formed by this method; passing from model to model is hazardous, causing the scale accuracy to deteriorate. Another method, which is more desirable, is that in which a normal run is made and all parallax is removed in the strip. By use of this method, the scale of the extension is more accurate. The T–11 and KC–1 cameras are equipped with an altimeter and a method of recording (on the negative) the altimeter readings at the instant of exposure. The recorded differences in altitude between exposures are fairly reliable and are used to advantage in the final adjustment of the extended elevations.

127. Multiplex Extension

Many factors affect the accuracy of an extension. Some of these vary so greatly that the resultant effect can only be estimated for a particular project. Numerous test extensions have been made with the multiplex equipment, using various cameras and camera-printer combinations. The results obtained give a good indication of the errors that will normally be encountered when the extension is made under favorable conditions. The errors are expressed as a fraction of the extended distance. As the start of the extension is no more accurate than the fixed control, any error in this control will increase the total.

a. Scale. The average error in scale in an extension of a single [illegible] be about $1/890$, and in 16 models [illegible]

[illegible]. The azimuth error in a single strip is greater than the error in scale. The extended strips follow a flat circular curve, sometimes to the left and sometimes to the right. Tests indicate this curvature is an instrumental error that varies with the camera-printer combination used, and is unpredictable for any particular combination. With one camera-printer combination, and with several strips of the same flight extended independently by four operators, the average curvature caused the center of a 16-model bridge, controlled at each end, to be deflected 2.8 mm from its true position. Subtracting this mean curvature from each strip extended, for this camera-printer combination, the remaining mean azimuth error for an extension of eight models was about $1/800$, and for 16 models was about $1/600$. The error due to this curvature is practically eliminated when the adjustment is made through two adjacent strips that were flown in opposite directions.

c. Resultant Error. The errors in scale and azimuth give a resultant error in position of $1/590$ for a single strip of eight models, and 1/445 when the extension is 16 models from the base control. Where the adjacent strips in a particular project are flown in opposite directions, and an adjustment can be made between strips, the accuracy of extended positions increases with the number of strips extended and adjusted together. Ordinarily, it is not practical to make a combined adjustment for more than six strips. Based on the above resultant error for an average strip, the probable error in position for various numbers of strips adjusted together is shown in table I. The elevation of each test strip was determined by making the assumption of a constant flight altitude and applying a correction to the extended multiplex elevation, as discussed in paragraph 82. The average error in elevation on the centerline of the strip at eight models from the base control was 0.9-mm with a range of error from 0 to 2.5-mm. At 16 models from the base control, the average error was 1.2-mm with a range of error from 0 to 3.0-mm. These errors are expressed in terms of the scale of the model. Points away from the centerline of the strip will generally be found to have additional errors due to tilt. This tilt, expressed as the difference in the height between the two edges of the model, averaged 0.8-mm at eight models out, with a range of error from 0 to 2.3-mm, and averaged 1.5-mm at 16 models out, with a range of error from 0 to 5.9-mm.

Table I. Typical Azimuth Error

Number of strips	Resultant accuracy	
	At eight plate pairs	At sixteen plate pairs
1	1:590	1:455
2	1:840	1:630
3	1:1000	1:770
4	1:1180	1:890
5	1:1330	1:1000
6	1:1450	1:1080

128. Multiplex Bridging

The errors in bridging are similar to the error of a multiplex extension, since bridging is a special case of extension wherein control is not furnished in every model, but does appear at both ends of any series of uncontrolled models. In bridging, the closing errors can be determined and adjustment made throughout the intermediate models.

a. Horizontal Accuracy. The position error in a bridged section will vary with the number of models in the bridge. The scale of the models and the flight altitude have no apparent effect. When the bridge can be accomplished at a smaller scale, using fewer models than for the detail plotting, greater accuracy can be obtained in the horizontal positions in the bridged sections. The results of tests show that a position accuracy of 30 meters will normally be obtained in bridges made to the scales and for lengths as listed in table II. The number of models that may be used in a bridge varies with the ratio of the reproduction scale of the plotting scale of the bridge. Based on the results of table II, the number of models that may be bridged satisfactorily at various reproduction scales is shown in table III.

Table II. Bridge Lengths

Mapping scale	Flight altitude (feet)	Number pairs	Distance (meters)
1:10,000	12,000	15	32,000
1:15,000	18,000	13	42,000
1:20,000	24,000	11	49,500
1:25,000	30,000	10	55,000
1:30,000	36,000	9	66,750

Table III. Number of Models Bridged

Publication scale	Number of models
Scale of extension	5
¾ extension	7
½ extension	9
¼ extension	13

ccuracy. As in single models, the vertical accuracy of bridging is more critical than the accuracy of horizontal positions. BZ curves must be used to adjust these elevations to the level datum; hence, the accuracy depends somewhat on the accuracy of the constant flight altitude assumption or the altimeter recordings when available. Additional corrections should be made for the tilt in the strip. Best results are obtained by using two elevations at each end of the bridged section, located near the edges of the strip. Tests show that bridges of 16 models can thus be made with errors not exceeding 1.5-mm, and with average errors of 0.4-mm throughout the strip. Shorter bridges reduce the range of error somewhat, but give about the same average error.

129. Cross Tilt

The phenomenon of cross tilt is particularly annoying in all multiplex triangulation. It is due to the inability to recover exactly the camera stations for successive pairs, which in turn is due to variations in the equipment or materials and imperfect relative orientation. Tests show that cross tilt can be eliminated when perfect diapositives (grid diapositives) are used, although some diapositives must be discarded. The main cause of cross tilt is imperfect orientation, due to the inability of the operator to remove all parallax in terrain models. When cross tilt occurs, a recheck of the relative orientations should be made. If this fails to help, the operator concludes that the diapositives are faulty and should be exchanged for a new set. In no case should the cross tilt exceed 0.5-mm when proper care is taken. Introduction of swing parallax will remove cross tilt, but will introduce an aximuth error. Several tests have shown that removal of all cross tilt by this method introduced a considerable bow in a strip containing 7 models.

Section IV. OPERATOR

130. Considerations

The ability to distinguish a difference in depth (stereoscopic acuity) varies with different people and the nature of the object observed. At normal reading distance (25-cm), it is possible to recognize depth differences between 0.05-mm and 0.15-mm. With a reasonably good image, the average accuracy with which an operator with acute stereoscopic vision can measure parallax is on the order of 0.10-mm. With magnification of image, the accuracy of measurement can be expected to increase in approximate proportion to the magnification. In the multiplex, where the average model is about 2½ times the scale of the 6 inch focal length photography, an average error of 0.05-mm of parallax measurement is equivalent to 0.02-mm at the scale of the photography. In the multiplex system, the perception of depth is made more acute by increasing the angle between intersecting rays seen by the eyes; this gives greater depth perception. In the process of contouring in a model, the operator makes a series of individual parallax measurements in rapid succession. The accuracy with which this can be done is somewhat dependent upon the image (sharp definition or low density variation). Training and practice improve the stereoscopic acuity of the individual.

131. Parallax

Improper orientation will cause a model to be tilted or warped. Consistently good results (within the optical accuracy of the system) can be obtained only by careful removal of parallax from the model. The ability to remove parallax varies with the stereoscopic acuity of the individual, the nature of the image, and the character of the floating mark.

132. Spot Hegihts and Contour Accuracy

With careful measurement, the elevation of a point in the model may be determined with an accuracy between 0.05-mm and 0.15-mm; however, the process of tracing contours is usually performed in a continuous, more rapid manner. Larger errors may thus be expected in contours, varying particularly with the terrain.

133. Multiplex Accuracy

No definite statement of multiplex accuracy will satisfy all cases in table IV. Many factors contributing to resultant errors vary so greatly that they can only be estimated for a particular project. Errors 1, 3, 4, and 5 in table IV are independent errors. The probability is against all of these errors occurring in any one place at the same time in any one model. The combination of these errors in a model should not exceed ± 0.2-mm. This is 1/1800 of the flight altitude and represents one-half of a contour interval. Therefore, the basic maximum accuracy of the multiplex system may be considered sufficient for a contour interval of 1/900 or 1/1000 of the flight altitude. However, this basic accuracy must be reduced in accordance with the other sources of error listed in the table below. For multiplex, the estimated accuracy may be considered sufficient for a contour interval of 1/600 of the flight altitude. A thorough investigation should be made of all errors found so that they can be prevented, and future map accuracy will be increased. As the inaccuracy is determined, the specifications defining methods to be used and the accuracy required can be revised to obtain even greater accuracy. Any increase in this usefulness of the multiplex method mapping.

Table IV. Possible Sources of Error

Source	Magnitude error
1. Aerial Camera, T-11, KC-1	±0.1-mm
2. Aerial Photography	Controlled by specifications.
a. Correct Exposure	
b. Weather (Cloud Cover)	
c. Flight Height	
3. Aerial Photographic Material	±0.1-mm
a. Film Negative	
b. Diapositive	
c. Processing	
4. Multiplex Equipment	±0.15-mm
a. Projector	
b. Tracing Table	
c. Cartographic Material (Stability)	

Table IV. Possible Sources of Error—Continued

Source	Magnitude error
5. Operator's Ability	±0.1-mm
a. Stereoacuity	
b. Manipulation of Motion	
c. Drafting Ability	
6. Control	Controlled by skill of personnel.
a. Primary Control—Order of Accuracy	
b. Aerotriangulation Control	
(1) Photographic Identification	
(2) Selection of Pass-Points	
7. Terrain	Varies with project.
a. Flat Terrain, Difficult to Contour	
b. Mountainous, Extreme Shadows	

Note. The above listed errors are not necessarily cumulative, but tend to cancel each other.

CHAPTER 9

ADAPTING MULTIPLEX EQUIPMENT FOR OBLIQUE PHOTOGRAPHY

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134. Introduction

The Air Force has made available to the Corps of Engineers extensive amounts of photographic coverage of the high oblique (60° from vertical) type. Standard multiplex equipment can be adapted to use this photography in the preparation of topographic maps. The modification of the multiplex equipment (app. VI) consists merely of adding two supplementary components, the tilt bar assembly and the condenser clamp. The tilt bar is an adjustable device which is secured between the bracket assembly and the projector body and allows the projector body to be tilted 20°, 40°, or 60° from the vertical. The 10° free motion of the projector body allows a full spread of 70° by the projector. The condenser clamp is a simple device for retaining the condenser assembly on the projector cone at extreme angles of tip. Figure 30 illustrates the oblique multiplex equipment.

135. Diapositives

The diapositives for oblique projection are prepared in the standard reduction printer in a manner similar to that used in [illegible] diapositives. However, it is ad- [illegible] the area toward the horizon progressively lighter, so the weaker illumination at this greater distance from the light source will not impair the visibility.

136. Plotting Sheets

For this method of mapping, the tilted projectors should be far enough away from the operator to permit plotting to approximately 10 inches beyond the principal point, but not so far away as to prevent the operator reaching the projector orientation screws. The desired portion of the model, at optimum plotting scale, will occupy approximately 60-cm of the 76-cm width of the multiplex table. Therefore, to prevent the plotting sheet from overhanging the front of the table, it must be laid out to completely cover the width of the usable portion of the model. To accomplish this, rectified oblique photographs should be outlined on a job index sheet containing the grid lines that will be used in laying out the plotting sheets. The job index sheet may then be indexed, with reference to the models and grid lines, and will

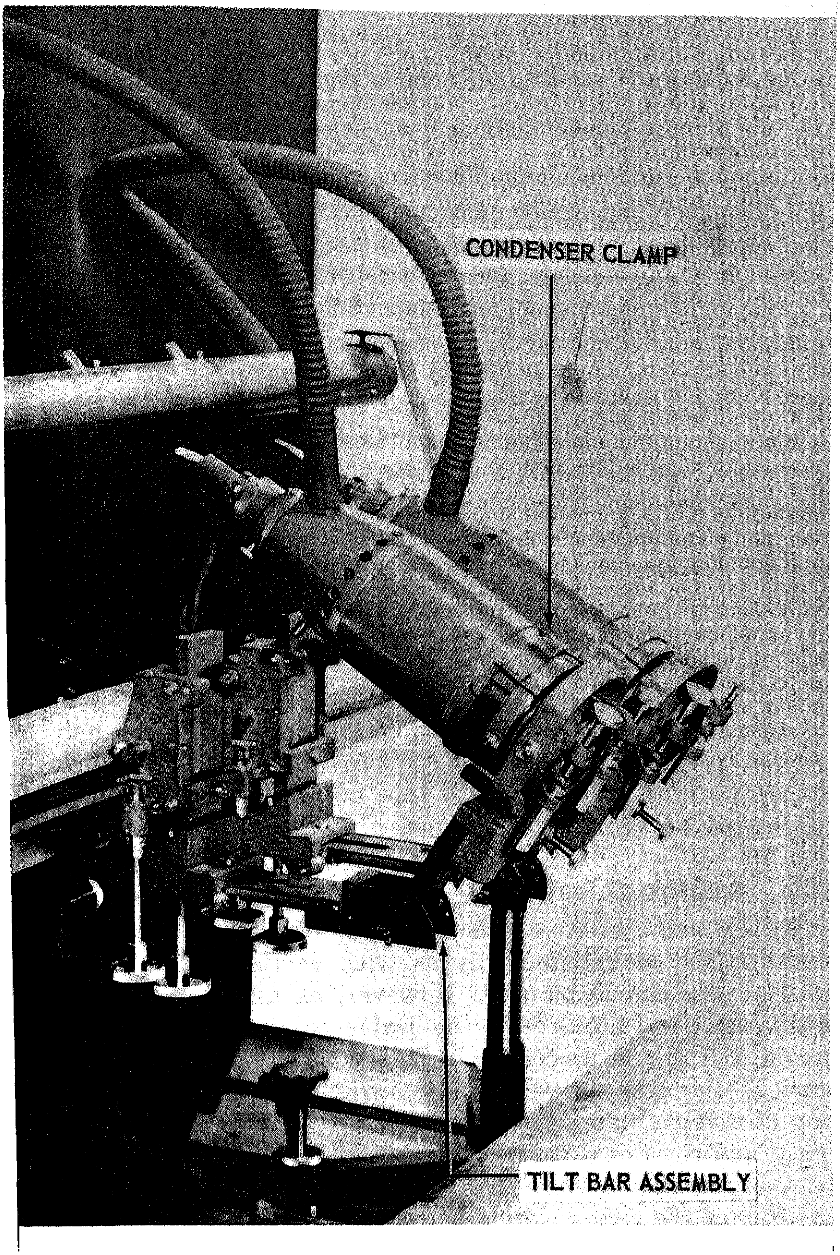

Figure 30. Oblique multiplex equipment.

serve as a guide in the plotting sheet layout operation. No attempt should be made to standardize the size or the positions of the sheets with respect to latitude or longitude, since these layouts are made primarily for plotting.

137. Plotting Scale

The optimum plotting scale for 60° oblique models is 1/1.3 times the flight altitude in feet. Thus for a flight altitude of 20,000 feet, the optimum plotting scale is $\frac{1}{1.3 \times 20{,}000}$ or 1:26,000. When photography is flown with 60 percent overlap, such a scale will permit 13-mm clearance between projectors. Overlaps greater than 60 percent will necessitate plotting the obliques at a larger scale. This may be done for the area inside the principal points, but the extent of the usable portion of the model beyond the principal points will decrease.

138. Steps Before Orienting

As with vertical photographs, it is advisable to insert diapositives in all the projectors at the bank to be set up, prior to starting the orientation operations. This is almost mandatory, because the projectors are not readily accessible, and it is likely that those models already oriented would be disturbed when adding a diapositive to an adjacent projector. All interior orientation should be made in successive steps. All projectors should be set equidistant from the bar, and as far as possible, at the same elevation. The bar should be leveled prior to orientation. Light should be checked to insure maximum illumination. This is extremely important for oblique projection. When the lights glare into the operator's eyes, strips of black tape can be used as shades over the top portion of the lens housings.

[illegible], [illegible] entation of oblique pairs cannot be accomplished as satisfactorily as with vertical pairs, since the entire model cannot be used. However, parallax can be removed within practical limits from the usable portion of the model. To accomplish this, a procedure is used which is fundamentally the same as that used for vertical photography. The relative orientation of oblique diapositives requires the use of the same translational and rotational motions as used in the vertical setup. However, in the adaptation of the vertical projectors to obliques, the freedom of the swing motion is lost and it is therefore necessary to use the general swing motion rather than the fine motion screw for removal of swing parallax. The fine motion screw can only be used when it is in opposition to the spring. While it is well for the operator to be familiar with the effect of each of the motions in oblique relative orientation, no detailed discussion will be given herein. However, after presenting the detailed procedure used to accomplish this orientation, a general discussion will follow in which certain significant conclusions are made for the benefit of operators not familiar with this method of mapping. The procedure is written primarily for multiplex operators experienced in mapping from vertical photography.

140. Parallax

Figure 31 illustrates the positions in the model which are selected for the removal of parallax. The procedure described is for the case where only one projector is moved, the other being kept stationary. In the figure, the movable projector is II, on the right. Position 1 is near the principal point of projector II; position 2 is between the principal point of projector I and the edge of the model on a line through the two principal points; position 3 is near the right corner of the short side of the model; position 4 is near the left corner of the short side of the model; position 5 is as far out into the oblique area as it is possible to dependably view the detail, approximately on a line perpendicular to the air base, through the principal point of projector II; and position 6 is analogous to 5, but on the other side of the model.

141. Procedure for Relative Orientation

The procedure for relative orientation is as follows: (All motions apply to projector II (right projector)).

a. Clear parallax at position 1 with *y*.

b. Clear parallax at position 2 with swing.

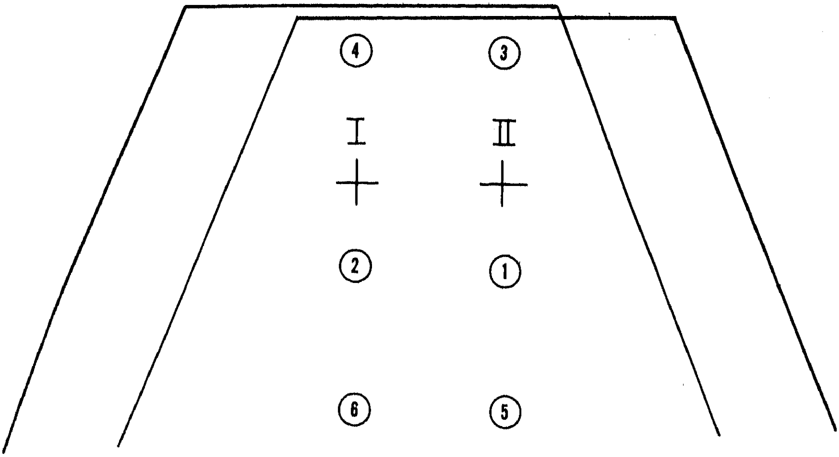

Figure 31. Positions in oblique model for parallax removal.

c. Repeat *a* and *b* above until positions 1 and 2 are cleared of parallax.

d. Clear parallax at position 3 with *y*.

e. Overcorrect parallax at position 1 (a very small amount) with *z*.

f. Repeat *d* and *e* above until positions 1 and 3 are cleared of parallax.

g. Check position 2. If parallax is present, repeat previous steps until positions 1, 2, and 3 are cleared of parallax.

h. Clear parallax at position 4 with *y* tilt. The resultant vertical change may be removed by either the *x* motion along the bar, or the tracing table.

i. Check positions 1, 2, and 3. If any parallax is present, repeat the above steps until positions 1, 2, 3, and 4 are cleared of parallax.

j. Overcorrect at position 5 (equal to the amount of parallax) with *x* tilt.

k. Repeat *d*, *e*, and *i* above until positions 1, 3, and 5 are cleared.

l. Check positons 2 and 4. If parallax is present, clear by swing or *y* tilt. Position 6 should then be clear of parallax. If any is present, however, repeat the entire process until all six positions are cleared of parallax.

142. Refinements

In the above instructions, as in relative orientation of vertical projectors, the objective is to orient one projector with respect to the other to produce a parallax free model. The order of the pro- [illegible] tion progresses, the parallax [illegible] by each succeeding procedure at positions already cleared will be reduced to a minimum. The effects of the *z* and *x* tilt motions are similar, and since the minimum effect of either of these motions is at the nadir point, position 3, which is as near the nadir point as possible, is selected as the zero point with respect to these two motions. Therefore, when parallax is removed at position 3 by *y* motion in paragraph 141*i*, the operator should observe the nature of the parallax pattern at positions 1 and 5. If the projectors were originally set perpendicular to the bar, parallel to each other, and the relative *y* tilt is not great, the nature of the parallax pattern at these points will indicate whether the *z* or *x* tilt motion should be used in the next step. If, for example, the parallax at position 5 is in the same direction as at position 1, but is more than about twice the parallax at position 1, or if the parallax at position 5 is in the opposite direction to that at position 1, an *x* tilt adjustment is needed. When positions 1, 2, and 3 are cleared as indicated in paragraph 141 *a* through *g*, it is necessary to remove the parallax at position 4 by *y* tilt motion, since it is almost impossible to clear positions 1, 3, and 5 simultaneously when the y tilt is present. Due to the fact that the y tilt axis of the projector is tilted 60° with respect to the table surface, the maximum displacement in the projection due to the y tilt motion occurs at position 5, therefore the y tilt motion adjustment is made to remove parallax at position 4.

143. Final Check

It is recommended that most of the adjustments in relative orientation be made by color separation; that is, without the filter spectacles. Only the final precise check of the model for parallax should be made with the glasses and the floating mark.

144. Absolute Orientation

a. Horizontalization. Absolute orientation of oblique models with respect to ground control is similar to that for vertical models. When horizontalizing, the tipping of the model with the oblique projectors is more difficult than it is with vertical projectors. Therefore, the oblique model should be approximately horizontalized during the relative orientation process. This is of greater importance than it is for vertical models. Tilting the oblique model, however, is not so difficult, nor is it necessary to tilt the model with the projectors alone because the wide tilt base permits use of the multiplex bar for this adjustment. It is advisable to approximately horizontalize the model within 1-mm i [illegible] direction and within 2-mm in the tilt direction, prior to the final relative orientation adjustments.

b. Scaling. As with horizontalization, the scale of the model should be made approximately correct during the relative orientation operations. Introduction of a large amount of x movement in a parallax-free model will result in a reintroduction of parallax.

145. Bridging

Bridging oblique models is similar to the bridging of vertical models. The third and succeeding projectors are oriented in turn, with respect to the previously oriented projector as described in paragraph 141.

146. Cross Tilt

Cross tilt is minimized by accurate removal of parallax as with vertical models. Attempts should be made to keep the cross tilt from exceeding 0.8-mm; however, due to the difficulty in viewing areas toward the horizon, this desired cross tilt accuracy may be difficult to achieve. As with vertical models, center pass points should be chosen on well-defined planimetric features as near as

possible to the principal points. Scaling the bridge is accomplished
in the usual manner of expanding or contracting the distances in
rojectors, using the center pass points and the
overall scale adjustments are necessary, the
echecked for parallax.

nce in oblique multiplex mapping that
ately brought into contact with the
the model and when plotting plani-
a lack of accuracy in this respect is
lique models. The reason is that the
ue model are so shallow that the hori-
is greater than the vertical displace-
loating mark is raised 0.1-mm above
point, the horizontal displacement
73-mm. Beyond the principal point
ncreases as the angle increases. In
effective angle in the *y* direction is
displacement, the horizontal shift is

I

not be identified and plotted very much beyond
oint of the oblique projection in the multiplex model.
o identify this detail is due, not alone to the falling
ss in the projection, but also in part to the flat angle
image points. In other words, this detail was not well resolved on the original aerial negatives. It appears, however, that out to the principal point, the accuracy of identification of planimetric detail is almost equivalent to that for a vertical model.

149. Accuracy

With adequate ground control, normal standards of accuracy may be obtained in medium scale maps with a contour interval of about 1/400 the flight altitude, using multiplex equipment converted to use of oblique photographs, provided the models are not exploited beyond the principal points.

CHAPTER 10

USE OF RECONNAISSANCE PHOTOGRAPHY IN MULTIPLEX MAPPING EQUIPMENT

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150. Background

The situation may arise, particularly during hostilities, when it is mandatory to map an area where the only existing aerial photographic coverage is of the reconnaissance type. Although it has been stressed in this manual that specific types of camera and film are the only ones suitable for photography for multiplex work, it is possible to produce a map from photography normally considered unsuitable, provided allowances are made for the limitations of the techniques involved. The entire technique of using reconnaissance photography in multiplex should be regarded only as a field expedient. A poor map produced when needed is better than none at all, or better than a good one made too late.

151. Nonstandard Focal Length Photography

As previously stated, multiplex equipment is designed to accommodate photographs made with a 6-inch focal length lens. Because of the design features of the projectors, projection distances are limited between 270-mm and 450-mm, with 360-mm being the optimum distance, and the minimum usable distance between projectors is limited to approximately 140-mm.

a. The projectors are designed so that the plane of sharpest focus in the projected image is 360-mm from the projector lens. Since the depth of field is from 270-mm to 450-mm, some variation in the scale of plotting is possible and points of high and low elevation within the model can be kept in good focus. Photographs having a forward lap of up to 70 percent can be set up at the minimum projection distance of 270-mm if the photography is of the focal length for which the projector was designed. This requirement was considered in determining the size of the projectors. The size of the projectors, in turn, establishes the minimum base distance (B_m) with respect to projection distance (P). Figure 32 illustrates this relationship. The minimum value permissible for the base-height ratio is equal to B_m/P when B_m is a minimum with the projectors as close together as physically possible, and P is the maximum usable distance. Also, from figure 32:

$$b = C/P \times B_m \qquad (1)$$

$$(2)$$

nd solving for F:

lap $B_p = 0.4W$, where W is the ne direction of flight. Therefore, , the expression for the maximum oretically correct conditions is:

$$= \frac{0.4W}{B_m\ (\text{minimum})}$$

ninimum reduction factor permissible

$$\frac{\text{inimum})}{PW}$$

It will be noted from these formulas that, as forward lap increases, B decreases and the maximum focal length usable decreases; as aches the maximum, the range of usable es. The formulas also define the limits of the ength and reduction. Assuming the use of 9-inch by atives having a 60 percent forward overlap, and assuming that the plotting is done at the projection distance of 360-mm, the wide angle multiplex equipment can be used for photography with focal lengths up to 9¼ inches and the minimum reduction factor can be as low as 0.12. Plotting at a projection distance of 450-mm, the maximum focal length can be extended to 11½ inches and the reduction factor lowered to 0.096.

b. To use photographs taken with lenses of nonstandard focal lengths that meet the above requirements, either of the two methods may be used in making the diapositives. These two methods are:

(1) Design and construct a special reduction printer for the particular camera-projector combination.

(2) Make the diapositives with the available enlarging-reducing camera or with a copy camera set to the required theoretical reduction.

c. The first of the two methods of *b* above is the more desirable when the quantity of the particular photography is sufficient to justify the construction of a reduction printer, built to give greater precision than can be obtained with available enlargers or copy cameras. However, results obtained by the second method can be quite satisfactory. Compensation for distortion in a copy camera

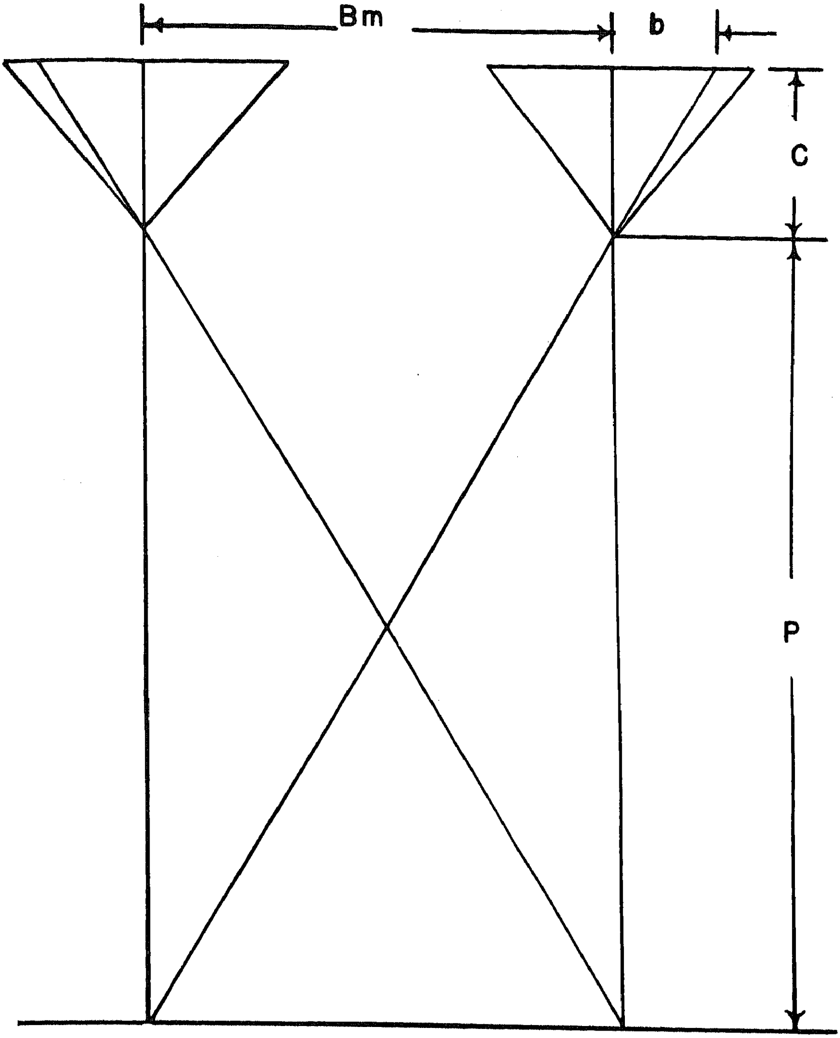


Figure 32. Relationship between base distance and projection distance in the multiplex model.

lens cannot be made by using this second method. Also, it is probable that other distortions affecting the plotting accuracy may be introduced.

d. When the equipment necessary for the methods outlined in *b* (1) and (2) above is not available, fair results may be obtained by using a printer that gives a reduction reasonably close to that

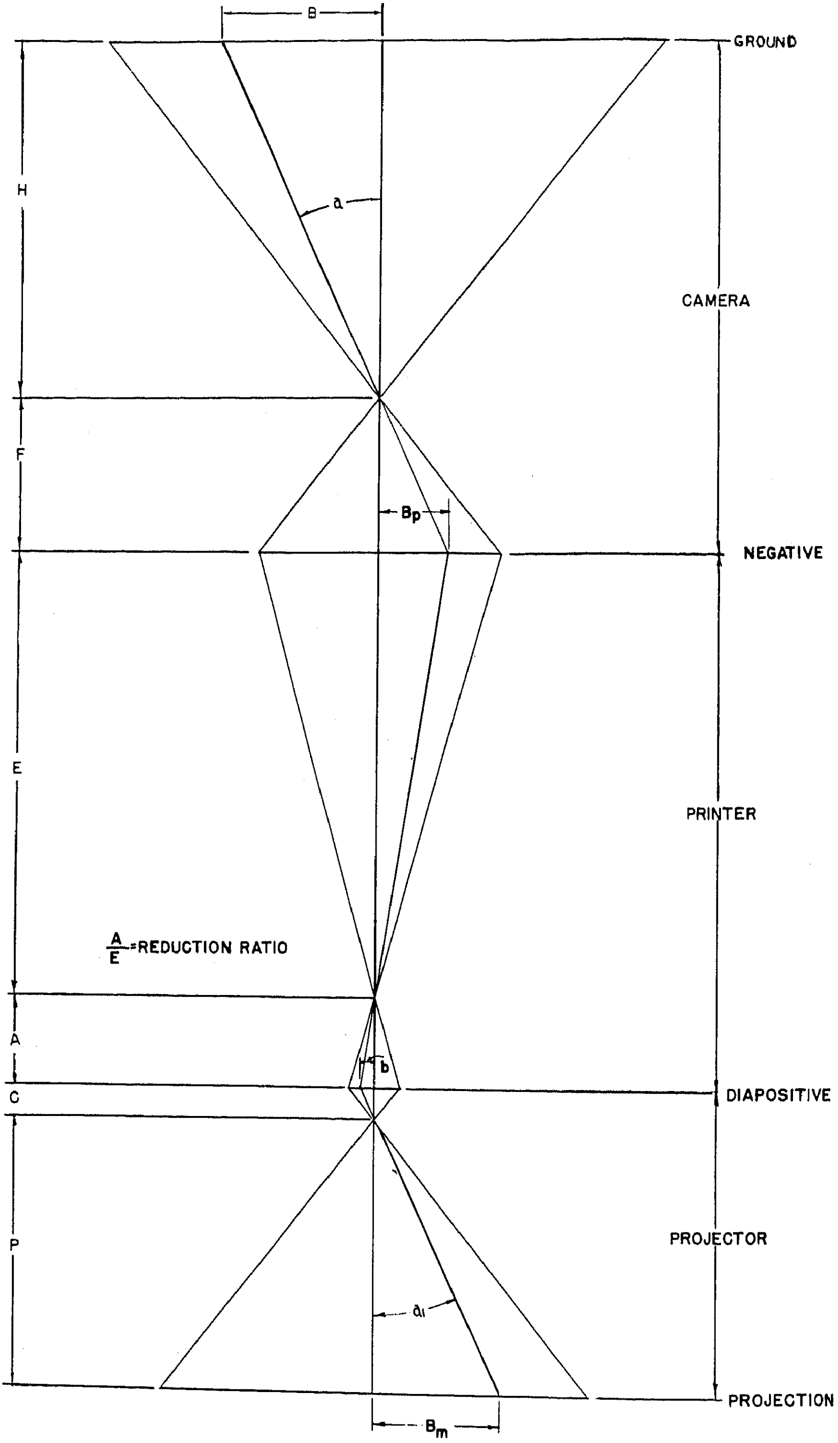
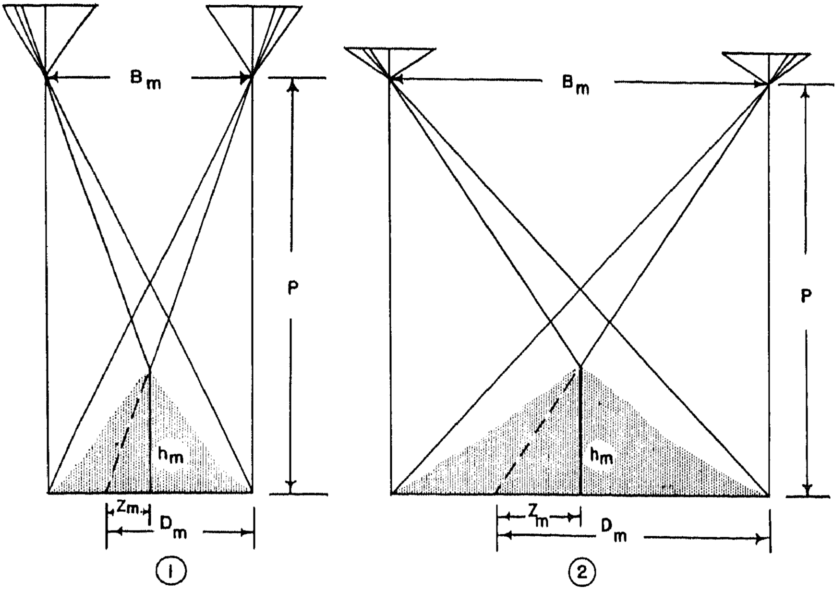


Figure 33. Relationship of the camera, printer, and projector.

required. Photography having focal lengths larger than the limits determined previously (K–18, 24-inch photography, for example) can be used in the multiplex only with a large error in the reduction factor. Should tilt exist in the photographs, large errors will be caused in the model, which will increase with the relief in the area. This photography is relatively unreliable and should not be used except to fill in small gaps in coverage obtained with standard mapping cameras.

152. Effect of Reduction Error on Multiplex Model

With truly vertical photography, the only effect that an error in reduction in the diapositive plates has on a multiplex model is to change the horizontal scale. One, figure 34 illustrates a multiplex model in which the reduction is correct, the principal distance of the diapositives being equal to the principal distance of the projectors. Two, figure 34 illustrates the model formed with the same diapositives used in 1, 34, but with projectors whose principal distances are less than standard for the correct reduction factor. The figure demonstrates that heights measured in the two models are the same, but the horizontal scales are considerably different.



① Correct reduction

② Incorrect reduction

Figure 34. The effect of an error in reduction on the multiplex model.

153. Horizontal Scale

The horizontal scale of the model, S_h, expressed as a representative fraction is B_m/B in which B_m is the distance between projectors and B is the distance between exposure stations when the photographs were taken. From figure 33:

$$B_m = B \times \frac{F}{H} \times \frac{A}{E} \times \frac{P}{C}$$

Therefore, the horizontal scale (S_h) is

$$\frac{B_m}{B} = \frac{F}{H} \times \frac{A}{E} \times \frac{P}{C}$$

154. Vertical Scale

The vertical scale of the model, S_v, expressed as a representative fraction is $\frac{h_m}{h}$ in which h_m is the height above datum measured in the model, and h is the height above datum on the ground. From 1, figure 34:

$$\frac{h_m}{P} = \frac{Z_m}{D_m}$$

In the perspective at the camera station

$$\frac{h}{H} = \frac{Z}{D}$$

in which D and Z are the horizontal distances on the ground corresponding to D_m and Z_m, respectively, in the model. Then:

$$S_v = \frac{h_m}{h} = \frac{PDZ_m}{H\,D_m\,Z}$$

$$\frac{Z_m}{Z} = \frac{D_m}{D}$$

and

$$S_v = \frac{P}{H}$$

155. When Horizontal and Vertical Scales Are the Same

From the preceding discussion, it is seen that the vertical scale in the multiplex model is a function of the projection distance and the flight altitude; whereas the horizontal scale is a function of the focal length of the camera lens, the flight altitude, the reduction in the printer, and the enlargement in the projector. The only situation in which the horizontal and vertical scales are the same is when $C/F = A/E$ (fig. 33) or when the angular relationship in the projector is the same as that in the camera.

156. Reduction Factors

From the expressions for S_v and S_H previously given

$$S_v = \frac{EC}{FA}$$

or

$$S_v = \frac{EC}{FA} \times S_H$$

substituting R_t (the theoretically correct reduction) for C/F, and R_a (the actual reduction factor) for A/E gives

$$S_v = \frac{R_t}{R_a} \times S_H$$

157. Reduction Ratio

For use of photographs made with cameras having nonstandard focal length lenses, diapositives should be prepared at a reduction ratio equal to the ratio between the principal distance of the projector and the principal distance of the aerial camera used. When equipment is not available to do this, or when the focal length of the camera is larger than the limits set by the minimum reduction ratio usable in the multiplex, diapositives must be prepared at a false reduction ratio. This will adversely affect the plotting accuracy. In such cases, the vertical scale in the model is different from the horizontal scale in a ratio which may be computed by the formula derived in paragraph 156, as follows:

$$S_v = \frac{R_t}{R_a} \times S_H$$

With truly vertical photography, the accuracy of plotting will not be affected materially by errors in reduction. However, with tilted photography the accuracy decreases with an increase in the reduction error. With large errors in reduction, the photography is useless except for filling in gaps in photographic coverage of the proper type.

158. Errors

With tilted photography and a reduction error in the diapositives, it is theoretically impossible to remove all parallax from the multiplex model. Practically, however, the parallax caused by small reduction errors will be negligible. As the difference between actual and theoretically correct reduction increases, the parallax becomes quite large and the resultant model is only an approximation. Actually, under such conditions there are an infinite number of model shapes which may be obtained from a pair of photographs, depending on which portions of the model are freed of parallax in the relative orientation process. By theoretical analysis, it can be shown that with errors up to about 5 percent in reduction, and tilt in the photographs not exceeding 3 the resultant multiplex model can be made reasonably free c parallax. Errors in the plot will be insignificant if a vertical scal correction, computed as indicated above, is applied. On the othe hand, if the error in reduction is large, even small tilts will caus larger errors.

159. Focal Length

An important fact not always realized is that the vertical scal in a multiplex model is the same for any given flight altitud regardless of the focal length of the aerial camera or the subsequent reduction in the preparation of the diapositive plates (assuming that the photography is vertical). Thus multiplex plottin accuracy is not increased by increasing the focal length of th aerial camera as is often erroneously assumed. In fact, withi certain limits, the accuracy with which elevations can be determined in a multiplex model actually decreases with an increas in focal length of the photography. This is because stereoscopi perception in the model is increased by increasing the base-altitud ratio, which is possible with wide angle photography with shorte focal length lenses.

160. Negative Inspection and Evaluation

a. During the negative inspection, exposures from the negatives should be selected to be used in the stereoscopic examination, by multiplex, of these selected models for detection of warpage, distortion, and negative quality within the model. The selection of these exposures and the test procedures are discussed below.

b. The object of the roll (stereo) test is to observe such factors as: model flatness, parallax elimination, evidence of distortion, the quality of diapositives that can be obtained, and the ability to carry pass points to the adjacent model. This test is made from exposures selected from the roll to show representative negative quality throughout the roll. Exposures are selected to give stereo models at approximately 30-exposure intervals. In addition, three exposures (or two models) are selected near the ends of each roll to test the ability to carry over pass points from one model to the other. If conditions warrant, a third "carryover" test can be made near the center of the roll, and additional exposures can be added to any of these models (by "leapfrog" method) to give a longer extension for a more detailed analysis.

c. The amount of control present and the suitability of natural terrain features for measuring purposes are factors to be considered when selecting exposures. Exposures are also selected from among those which had previously been conditionally rejected because of negative density or negative damage.

d. The following is a guide for consideration in the performance of the roll (stereo) test.

(1) For tests to evaluate model flatness, parallax elimination, distortion, and carryover ability, exposures should be selected with the following representative conditions:

(*a*) Areas with meandering streams and rivers, or with canal developments.

(*b*) Areas having relatively flat portions, such as large rice paddies, marshes, swamps, and wide river valleys.

(*c*) Exposures that will produce models with long shorelines. Sufficient land mass should appear in the model to allow orientation.

(*d*) Extensive cultural areas having some of the above features.

(*e*) Exposures that will produce models containing well-distributed, photoidentifiable points of known elevation. If such a model is to be evaluated solely on the
basis of this control,
sary, 1 in each corner an
are desirable.

(2) To test negative quality
posures of the following typ

(*a*) For the density test, the
should be representative of the thinnest and densest exposures in the flight. Dense, or thin, negatives throughout the flight generally have the same comparative density.

(*b*) Exposures selected for the density check should be representative of exposures having discolorations and excessive denseness, thinness, flatness, and contrast. Exposures selected over well-developed areas or over areas having intricate hypsography will produce desirable models for proper evaluation of the amount of detail that can be defined.

(3) For evaluation of damaged negatives, the test exposures should represent the worst that can be found in the flight. These exposures should be selected in conjunction with the exposures selected for tests for flatness, parallax elimination, etc.

(4) Representative exposures selected for examination of negative damage should include those exposures with such defects as scratches, water spots, pinholes, bubbles, stains, and dirty emulsion. Such exposures must be care-

fully inspected when the evaluator believes that the defects may be critical.

(5) After selection of the exposures to be used, diapositive plates are made. The diapositive plates should be inspected to insure that they are of the best possible quality that can be expected from the film.

(6) The text models are set up by multiplex. Orientation is accomplished by leveling on available control on such natural features as lakes, shoreline, meandering streams and rivers, or relatively flat areas. The models are then examined for incongruous hypsography, visible warpage of the model, illogical terrain formations, and parallax that cannot be eliminated. The negative quality is examined to insure that proper density has been obtained to define hypsographic and planimetric detail accurately. Further evaluation is made to determine the suitability of the photography for control extension.

(7) When no defects are found in any of the models tested, or where the defects found are not cause for rejection, it is assumed that the remaining exposures of the roll are acceptable. If all the models tested are distorted, the entire roll may be rejected. However, where one or two models are rejected and the remaining models are free of [illegible]t is necessary to make additional tests in order to [illegible]e acceptable portions of the roll.

CHAPTER 11

DIAPOSITIVES

161. Accuracy

a. As the success of the multiplex operation depends largely on the quality of the diapositives, utmost care must be taken in their preparation. The accuracy of the final multiplex product can be affected, and the time necessary for its completion can be greatly increased through poor phototechnique or improper handling of the diapositive plates in the process of preparation.

b. The process photographer should thoroughly familiarize himself with the construction of the reduction printer (par. 12), and the special precautions necessary in its use.

162. Equipment

The equipment necessary for making diapositives consists of the following:

a. Reduction printer.
b. Photographic tanks for developing, fixing, and washing.
c. Racks for drying.
d. Thermometer.
e. Interval timer.
f. Continuous timer.
g. Exposure meter (desirable, but not necessary).
h. Camel's-hair brush, lens tissue, and lens cleaner.

163. Diapositive Plates

The diapositive plates should be of the best quality obtainable with a relatively fine grain emulsion which does not creep or peel. These plates are procurable commercially as plates, diapositive, coated with lantern slide emulsion, with antihalation backing, on specially selected flat glass, 1.50-mm ± 0.15-mm thick, 54.3 by 54.3 ± 0.5-mm in size. Contrast plates can be used with practically all aerial negatives. Medium plates are desirable with high contrast aerial negatives.

164. Developing Solutions

a. Considerations. In the course of time, the photographer must prepare diapositives from all qualities of negatives; of strong or weak contrast, and of high or low density. No one photographic developer is uniformly satisfactory in all cases. The process photographer should remember this, and should standardize on a developer and developing technique for use with each different type of negative. In any case, the developer should be of a type that will retain the resolving power of the diapositive emulsion. Only one grade of contrast is generally used for diapositive plates, so the desired contrast in the diapositive must be obtained by varying the developer or the developing time, preferably the developer.

b. Developers. Developers used in DA Supply Manual SM 5–4–6675–S21 set FSN 6675–41–3621 are Armed Forces Developer No. 25, Mil Spec D–4827B (D–72 metol-hydroquinone), Armed Forces Developer No. 3, Mil Spec D–4826B (D–76 metol-hydroquinone-borax), and DK–60A. (Organizations will normally use developers used in the set and will mix their own developers only in an emergency.) For use, these developers are dissolved in water as specified on the container. Chemical formulas are also available for mixing different developers from the separate chemicals. For the production of diapositives, it has been found that two types of developers will give all the control of contrast and density required. The developers are described below:

(1) *DK–60A.* Mix in the order given. Dissolve each before adding next ingredient. Cool to 67° F. Keep in full stoppered bottles and store in a cool place. Develop for 9 minutes at 67° F.

	U.S. Liquid	*Metric*
Water (125° F.)	96 ounces	750 cc
Elon (metol)	145 grains	2.5
Sodium sulfite (desiccated)	6¾ ounces	50.0
Hydroquinone	145 grains	2.5 grams
Kodalk or borax	2 oz. 290 grains	20.0 grams
Potassium bromide	29 grains	0.5 grams
Water to make	1 gallon	1.0 liter

(2) *AFD No. 25, Mil Spec D–4827B (D–72 metol-hydroquinone).* This is a universal developer suitable for the development of films, diapositives, contact prints, and enlargements. It is quick acting, completing its work in 2 to 4 minutes. The chemicals are dissolved to form a stock solution which is normally diluted for use. For negatives of low contrast, the undiluted stock solution will increase the contrast in the diapositive. For negatives of normal contrast, one part of the stock solution should be diluted with one to four parts water. For extremely contrasty negatives, it may be necessary to dilute one part of the stock solution with as much as 12 parts water. The stock solution has good keeping qualities when bottled and securely corked. When exposed to the air, the developer breaks down quite rapidly.

(3) *AFD No. 3, Mil Spec D–4826B (D–76 metol-hydroquinone-borax).* This developer is for use with films and plates only. It is a relatively slow acting developer requir-

ing about 12 to 15 minutes to do its work. The solution is normally used full strength, although it may be diluted for diapositives made from negatives with extreme contrast. This developer has good keeping qualities and may be used over a period of several days if kept covered when not in use.

(4) *Formulas.* For those who desire to mix their own chemicals, the following formulas are given:

AFD No. 25, Mil Spec D–4827B (D–72 metol-hydroquinone)

	U.S. Liquid	*Metric*
Water (125° F.)	64 ounces	500 cc
Metol or elon	175 grains	3.0 grams
Sodium sulphite	6 ounces	45.0 grams
Hydroquinone	1 oz. 260 grains	12.0 grams
Sodium carbonate	10½ ounces	80.0 grams
Potassium bromide	115 grains	2.0 grams
Water to make	1 gallon	1.0 liter

Thoroughly dissolve each chemical in the order listed before adding the next chemical. This is a stock solution which is normally diluted for use ((2) above).

AFD No. 3, Mil Spec D–4826B (D–76 metol-hydroquinone-borax)

	U.S. Liquid	*Metric*
Water (125° F.)	96 ounces	750 cc
Metol or elon	115 grains	2.0 grams
Sodium sulphite	13¼ ounces	100.0 grams
Hydroquinone	290 grains	5.0 grams
Borax (sodium borate)	115 grains	2.0 grams
Water to make	1 gallon	1.0 liter

Thoroughly dissolve each chemical in the order listed before adding the next chemical. This solution is normally used full strength ((3) above).

c. Fixing Bath (F–5) or Equivalent. After the diapositive is developed, it must be fixed to retain the image on the plate. The chemicals for the fixing bath are obtainable in prepared form, for dissolving as specified on the container. For those who desire to mix their own chemicals, the following fixing bath formula is given:

	U.S. Liquid	*Metric*
Water (125° F.)	89 ounces	600 cc
Sodium thiosulphate (Hypo)	32 ounces	290.0 grams
Sodium sulphite	2 ounces	15.0 grams
Acetic acid (28 percent)	6 ounces	48.0 cc
Boric acid crystals	1 ounce	7.5 grams
Potassium alum	2 ounces	15.0 grams
Water to make	1 gallon	1.0 liter

Thoroughly dissolve each chemical in the order listed before adding the next chemical. This solution is used full strength. The solution can be used over a considerable period of time.

d. Temperature of Solutions. The temperature of all solutions used in the production of diapositives should be about 68° F. (20° C.). At temperatures below 50° F., the chemicals in the developers fail to work properly, and possibly no image will be developed on the plate. At high temperatures, the emulsion on the plate will be softened excessively, causing distortions in the image.

165. Setting Reduction Ratio

The ratio in the reduction printer must be of the principal distance of the multiplex projector to the principal distance of the aerial camera, so that the angular relationship at the camera lens at exposure is exactly recovered in the projection. As described in paragraph 12*a*, the reduction ratio can be varied in the reduction printer. Before printing diapositives, both knurled rings must be set at the calibrated focal length of the camera with which the photography was performed, so the printer will be in focus and the diapositives will have the correct principal distance for use in the projectors. Both rings are always set at the same figure. Although the 6-inch, K–17 camera is not considered a precision mapping camera, there will be occasions when photography from this camera is all the coverage available, in which case the equivalent focal length (in millimeters) should be requested from the agency performing the photography. The focal length is stamped on the lens mounting ring of these cameras. When photography has been accomplished with the T–5, T–11, KC–1, and KC–18 cameras, the calibrated focal length (in millimeters) will be recorded photographically on the film.

166. Orienting the Negative

To place the roll of aerial negatives in the printer, remove the dome and upper pressure plate and examine the surface of the pressure plates to see that they are clean and free from dust. Engage the film spool in one bracket, draw the film (emulsion down) across the lower pressure plate, and attach to an empty spool in the other bracket. Then replace the upper pressure plate and dome. The proper interior orientation is obtained by alining the fiducial marks on the film with the collimating lines on the lower pressure plate. This alinement is made while observing the negative and the collimating lines on the lower pressure plate through the inspection windows in the dome. To move the film, raise the upper pressure plate by use of the foot treadle. The film may then be moved between the pressure plates without any undue strain. Aline the fiducial marks on the film with their corresponding collimating lines on the lower pressure plate, then release the upper pressure plate to clamp the film. A final check of the alinement must be made after clamping. It may be necessary to adjust the negative several times before absolute coincidence is attained between the fiducial marks and the collimating lines. At times it may be found impossible to bring all four fiducial marks into absolute coincidence with the collimating lines, or dirt may have lodged in a fiducial mark in the camera so the mark is somewhat obscured. In such instances, it is best to use only three marks for the orientation and to be consistent in using these three marks in orienting all negatives of the flight.

167. Density Control

a. Generally, aerial photographic negatives are more strongly exposed in the center than in the corners. Inspection of the film will give the process photographer an idea of the density difference throughout the exposure in question.

b. It is desirable to have diapositives of uniform density throughout, so the intensity of the light projected through the center of an aerial negative must generally be greater than that projected through the corners. To accomplish this, the printer is equipped with a compensating lens. By raising the compensator to the top of its travel, the minimum intensity of light in the corners is obtained. An experienced operator can judge by examining the negative where the compensator should be set for best results. For the beginner, a few trial exposures at variou
the compensator will indicate which should be used.

c. Illumination in the reduction printer is providec
of argon lamps, each of which is controlled by an on-off s
that diapositives with uniform photographic density can
pared readily from aerial negatives with variations in density. Particular variations in density are compensated by turning out the individual lamps under the thin or transparent portions of the negative to balance the light coming through the different areas.

d. Other variations in density (due to the altitude of the sun at exposure, variations in the type of terrain depicted, or other causes) cannot be compensated with the compensator lens or illumination control. These density variations can be improved only by proper shading or dodging. This is a difficult task and only practice will enable the photographer to dodge satisfactorily. Dodgin disks or wands are inserted through the slot or dodging windo just above the pressure plate.

168. Exposure and Processing

a. A good diapositive is free from streaks, marks, or other blemishes and may have the appearance of a soft pencil sketch.

A usable plate looks weak to the eye with transmitted light. The finest detail of the terrain, including that in the deepest shadow as well as the strongest highlight, must be recorded while holding the contrast to a minimum. A diapositive with excessive contrast is unsatisfactory. It is essential that all diapositives be of the same average contrast and density; otherwise, the multiplex operator is forced to vary the illumination of his projectors continually.

b. In general, any one roll of film has similar contrasts in each negative, but the densities may vary. This may require a different exposure time for each negative to get uniform diapositives. An experienced process photographer is able to judge closely the proper exposure, developer, and development time; but where experience with a similar type negative is lacking, trial exposures must be made to determine the proper treatment. If the trial exposures are made for those negatives having the highest and lowest densities, the exposure time for other negatives in the strip may be determined by using an exposure meter.

c. To use the exposure meter, remove the dome from the printer and place the meter on the center of the pressure plate. Raise the upper pressure plate by means of the foot treadle and run the
e meter reading at the center
(between the exposure times
of highest and lowest densities)
ange in meter readings, the exposure
egatives may be determined.

d. When ready to expose the diapositive plate, extinguish all light and use only the red safe light recommended by the diapositive manufacturer. Secure an unexposed plate and remove all particles of dust and lint by gently stroking with a camel's-hair brush. Place the diapositive, emulsion down, on the diapositive stage and press it firmly against the stops provided on one end and one side of the stage opening. While holding it in this position, place the clips over the diapositive to hold it in place while the exposure is made. A felt-covered weight about the size of the diapositive and weighing approximately one-half pound may be used instead of the clips. It is extremely important that the diapositive be in perfect contact with the stage. Expose the plate by turning on the light in the printer. After proper exposure time, extinguish the light and carefully remove the plate. Handle the plate with the thumb and fingers in contact with its edges. The diapositive is then ready to be developed.

e. The plate should be fully developed in accurately mixed developer held to the correct temperature. Time may be conserved by developing several plates simultaneously.

f. After developing, the plate should be rinsed in clear running water at 65° F. and then fixed for 10 minutes. The fixing bath should be freshly mixed, free of impurities, and of the same temperature as the developer. After fixing, the plate must be washed in clear, cool, running water for about 30 minutes. In washing, it is necessary that the water be absolutely clean. If there is sediment present, it may scratch or adhere to the plate. This does not always render the plate useless, but may cause the multiplex operator considerable annoyance.

g. Best results are obtained by air drying the plates in racks to allow all of the solution to drain off and dry on both sides at the same time. Grain or denatured alcohol is used to speed the drying process. Wood alcohol should not be used because of its toxic effect. After washing, immerse and agitate the plates in alcohol for 60 seconds. Remove from the alcohol and allow surplus alcohol to drain off to one corner. At this point it is permissible, where necessary, to swab the emulsion very lightly with a cotton swab saturated in alcohol. At no time should the emulsion be touched with the fingers. Then place the diapositive, emulsion side up, on the table or a piece of cardboard for drying.

h. The photographer must constantly realize the necessity for handling the plates with extreme care. Minute displacements introduced in the emulsion by improper handling cause distortion in the multiplex model, making it impossible to remove all parallax. If the water for washing is clean and the "hypo" and developer are fresh and free from impurities, there is no necessity for swabbing the emulsion side of the plate.

i. A process photographer who has had some experience as a multiplex operator is able to produce better plates as a result of the experience. A limited amount of training in multiplex operation is therefore recommended for process photographers.

169. Silicone Spots

A new process for making clothing and other fabrics water repellent is based on the use of silicones, and cloth so treated is available on the market under numerous trade names. While it is an effective treatment for rendering fabrics water repellent, this treatment has been found to present problems to the photographic industry and to those who use photographic materials. It has been found that silicones used for cloth treatment will fog some photographic films and papers rapidly. If lint from a silicone treated garment gets into contact with motion picture print film, for instance, and is held in contact with it overnight, black spots will show when the film is developed. So far the silicone treatment has been applied to garments such as raincoats, slacks, skirts, jackets, etc. It is expected, however, that it will be used on military uniforms and nonclothing items such as seat covers, upholstery fabrics, and drapes. The sensitivity of photographic materials to silicone fogging varies a great deal. If films are held at elevated temperatures or high humidities (above 70%), this sensitivity is greatly increased. The photographic materials most readily affected are Motion Picture Print Film, Aero Films, Micro Films, and papers used for photostat work. Loss of photographic materials can be minimized if users realize the possibility of danger and take precautions to prevent the wearing of silicone treated garments in areas where photographic films and papers are used. Suspected clothing may be tested for silicone treatment by rolling a thread or fibers scraped off the cloth in several tightly wound laps of Fine Grain Cine Positive or Kodagraph Print Film. The roll should be sealed in a container such as a well taped can, and kept overnight at about 120° F. or 3 days at room temperature. Normal processing will show a fogged pattern corresponding in position to the thread or fiber if the cloth has been silicone treated. It has been found that washing the hands will remove silicone transferred from clothes to hands during normal handling of garments.

APPENDIX I

REFERENCES

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1. Army Regulations

AR 117–5	Military Mapping and Surveying
AR 320–5	Dictionary of United States Army Terms
AR 320–50	Authorized Abbreviations and Brevity Codes
AR 345–20	Release from
AR 360–5	Genera
AR 380–5	Safegua
AR 743–108	Storage

2. Department of the Army Pa

DA Pam 108–1	Index of Army Motion Pictures, Film Strips, Slides, and Phono-Recordings
DA Pam 310–1	Military Publications: Index of Administrative Publications
DA Pam 310–3	Military Publications: Index of Training Publications
DA Pam 310–4	Index of Technical Manuals, Technical Bulletins, Supply Bulletins, Lubrication Orders, and Modification Work Orders
DA Pam 310–5	Military Publications: Index of Graphic Training Aids
DA Pam 310–7	Military Publications: Index of Tables of Organization and Equipment, Type Tables of Distribution, and Tables of Allowances
DA Pam 310–25	Military Publications: Index of Supply Manuals, Corps of Engineers
JSC Pub 1	Dictionary of United States Military Terms for Joint Usage.

3. Field Manuals

FM 5–188	Engineer Topographic Units
FM 21–5	Military Training
FM 21–6	Techniques of Military Instruction
FM 21–26	Map Reading
FM 21–30	Military Symbols

FM 21–31	Topographic Symbols
FM 101–10	Staff Officers' Field Manual: Organization, Technical, and Logistical Data

4. Technical Manuals

TM 5–230	General Drafting
TM 5–231	Mapping Functions of the Corps of Engineers
TM 5–234	Topographic Surveying
TM 5–236	Surveying Tables and Graphs
TM 5–240	Map Compilation, Color Separation and Revision
TM 5–241–1	Grids and Grid References
TM 5–243	Cartographic Aerial Photography
TM 5–245	Map Reproduction
TM 5–248	Foreign Maps
TM 5–6675–209–15	Tracing Table, Stereoplotter, Projection
TM 30–246	Interpretation of Aerial Photographs

5. Technical Bulletins

TB ENG 305	Identification, Inspection, and Classification of Multiplex Instruments

6. Army Map Service Publications

AMS TM No. 23	Symbols for Large Scale Maps at One-Fifth Reduction
AMS TM No. 23a	Symbols for Large Scale Maps at No Reduction
AMS TM No. 35	Compilation Procedures for Domestic Maps
AMS TM No. 45	Compilation Procedures for Foreign Maps

7. Motion Pictures, Film Strips, Slides, and Phono-Recordings

TF 5–1546	Multiplex Mapping, Part II
TF 5–1549	Multiplex Mapping, Part I
TF 5–1792	Photo and Photomaps

8. Other Publications

Multiplex Plotter Procedures, Geological Survey Topographic Instructions, Book 3, Chapter 3F4, United States Department of the Interior (1960).

APPENDIX II

MULTIPLEX AND PICTURE DATA FOR 6″ CAMERA

Multiplex plotting scale	Contour interval in feet		Flight altitude in feet for		Value of 0.1 MM in feet at plotting scale	Value in MM of contour interval		
	$\frac{1}{500}$ alt	$\frac{1}{1000}$ alt	Optimum projection plane	Minimum and maximum projection planes		10′	20′	50′
1:2400	5.7	2.8	2840	2210-3540	0.8	1.27	2.54	6.35
1:3600	8.5	4.3	4260	3310-5310	1.2	0.85	1.69	4.23
1:4000	9.5	4.7	4730	3490-5910	1.3	0.76	1.52	3.81
1:4800	11.3	5.7	5670	4410-7090	1.6	0.64	1.27	3.18
1:5000	11.8	5.9	5910	4590-7380	1.6	0.61	1.22	3.05
1:6000	14.2	7.1	7100	5510-8860	2.0	0.51	1.02	2.54
1:7000	16.5	8.3	8270	6430-10330	2.3	0.44	0.87	2.18
1:7200	17.0	8.5	8510	8620-10620	2.4	0.42	0.85	2.12
1:8000	18.9	9.5	9460	7350-11800	2.6	0.38	0.76	1.90
1:8400	19.9	9.9	9930	7720-12390	2.8	0.36	0.73	1.81
1:9000	21.3	10.6	10630	8270-13270	2.9	0.34	0.67	1.69
1:9600	22.7	11.3	11340	8820-14160	3.1	0.32	0.63	1.59
1:10000	23.6	11.8	11820	9190-14760	3.3	0.30	0.61	1.52
1:12000	28.4	14.2	14130	11030-17700	3.9	0.25	0.51	1.27
1:14000	33.1	16.5	16540	12860-20650	4.6	0.22	0.43	1.09
1:14400	34.0	17.0	17000	13230-21250	4.7	0.21	0.42	1.06
1:15000	35.4	17.7	17710	13720-22130	4.9	0.20	0.41	1.02
1:16000	37.8	18.9	18900	14700-23600	5.2	0.19	0.38	0.95
1:18000	42.5	21.3	21270	16540-26550	5.9	0.17	0.34	0.85
1:20000	47.2	23.6	23620	18380-29520	6.6	0.15	0.30	0.76
1:22000	52.0	26.0	25980	20220-32470	7.2	0.14	0.28	0.69
1:23000	56.7	28.3	28330	22050-25420	7.9	0.13	0.25	0.64

The contour interval plottable to the customary accuracy of ± ½ contour interval will be between and the distance of the plotting from the optimum projection plane.

FORMULAE AND CONSTANTS FOR WIDE

Focal length = 6″
Focal plane size = 9″ x 9″
Angular coverage across 9″ focal plane axis = 73° 44′
Angular coverage across focal plane diagonal = 93° 22′
Length of one picture (in miles) = 0.0000284 x Alt in ft

APPENDIX II

MULTIPLEX AND PICTURE DATA FOR 6″ CAMERA

At altitudes for optimum projection plane

Scale of picture	Net forward gain per model in miles at 60% overlap	Width of one photo in miles	Area covered in one picture in square miles	Area of net model at 60% forward overlap and 20% side overlap	Flight line spacing in miles for side overlap		Number of pictures per 10 mile strip with 60% forward overlap
					20%	30%	
1:5680	0.32	0.81	0.65	0.208	0.64	0.56	30.96
1:8520	0.48	1.21	1.46	0.468	0.97	0.85	20.66
1:9460	0.54	1.34	1.81	0.577	1.07	0.94	18.59
1:11340	0.64	1.61	2.59	0.830	1.29	1.13	15.53
1:11820	0.67	1.68	2.82	0.902	1.34	1.17	14.88
1:14200	0.81	2.02	4.07	1.302	1.61	1.41	12.39
1:16540	0.94	2.35	5.52	1.766	1.88	1.64	10.64
1:17020	0.97	2.42	5.85	1.871	1.93	1.69	10.34
1:18920	1.07	2.69	7.22	2.310	2.15	1.88	9.20
1:19860	1.13	2.82	7.96	2.546	2.26	1.97	8.86
1:21260	1.21	3.02	9.12	2.916	2.42	2.11	8.28
1:22680	1.29	3.22	10.38	3.322	2.58	2.25	7.76
1:23640	1.34	3.36	11.28	3.608	2.69	2.35	7.45
1:28360	1.61	4.03	16.24	5.20	3.22	2.82	6.21
1:33080	1.88	4.70	22.08	7.066	3.76	3.29	5.32
1:34000	1.93	4.83	23.32	7.462	3.86	3.38	5.18
1:35420	2.01	5.03	25.31	8.099	4.02	3.52	4.97
1:37800	2.15	5.37	28.83	9.224	4.29	3.76	4.65
1:42540	2.42	6.04	36.52	11.686	4.83	4.23	4.14
1:47240	2.68	6.71	45.02	14.408	5.37	4.70	3.73
1:51960	2.95	7.38	54.48	17.433	5.90	5.17	3.39
1:56660	3.22	8.05	64.77	20.703	6.44	5.63	3.11

$\frac{1}{500}$ and $\frac{1}{1000}$; the altitude, depending upon the quality of the photographs, the contrast in the terrain,

ANGLE MULTIPLEX RELATIONSHIPS

Alt (in ft for optimum) = 1.182/plotting scale

Alt (in ft for minimum) = 0.919/plotting scale

Alt (in ft for maximum) = 1.477/plotting scale

Picture scale = $^{1}/(2 \times \text{alt in ft})$

Area covered by one picture (in sq mi) = 0.0807 (Alt/1000)^{2}

APPENDIX III

FLOATING CROSS USED IN RELATIVE ORIENTATION

1. A cross to replace the floating dot in the operation of removing *y* parallax from multiplex models has been used in Canada and Europe for many years.

2. The cross consists of two right-angle black lines which are turned so the legs are approximately 45° to the operator's eye base. When viewed within a stereoscopic model, the cross floats up or down with the tracing table platen in the same manner as does the floating dot of light. The presence of *y* parallax, however, causes one of the lines to appear higher than the other. Parallax can be removed by the adjustment of appropriate projector movements until the two lines of the cross are brought to the same elevation.

3. A test was conducted in which an operator of considerable experience used the dark cross and the dot of light in removing *y* parallax. During the first week of trial the last traces of parallax proved difficult to remove by reference to the cross and preference for the dot of light was expressed. However, as experience was gained, the advantages of the cross became more and more apparent. The dot of light was referred to only in rare cases where portions of a model were extremely dark. A more accurate solution for relative orientation can be obtained by reference to the cross. The inertia of skilled technicians in resisting the use of new and unfamiliar methods must be overcome. The training of new operators in the removing of *y* parallax is facilitated by the use of the cross.

4. The most satisfactory cross consists of two right-angle black ink lines intersecting at their midpoints. The lines must be about 2.5-cm long by 0.125-mm wide and they must be clear-cut and sharp. The cross is drawn on a small piece of white paper and is laid on the platen to one side of the dot of light, thus permitting the selection of either reference mark. In this way the cross can be removed while map detail is being compiled. Experience has shown that the cross must be kept in exact contact with the model surface while *y* parallax is being removed. The illusion of separation between the lines of the cross when *y* parallax is present is explained by the fact that each eye of the operator sees the cross at a different place. The lines are immediately fused into a single image, but the legs appear at a different elevation because along one leg the "blue" line is on the right of the "red" line and along the other leg the "blue" line is to the left.

APPENDIX IV

STEREOVISION TESTS

1. Introduction

Good stereoscopic vision is a basic requirement of all multiplex operators. Stereoscopic vision is common to most people, but in varying degrees. Those who have good stereovision do not develop it further in the daily routine of life; but, with the proper training or with the aid of prescribed glasses, it may be developed to the standard requirements of a multiplex operator.

2. Purpose

The eye tests are given to a candidate for multiplex training in order to evaluate his ability to perform certain basic functions involving stereoscopic perception. This evaluation is based on tests showing:

a. Ability to see stereoscopically by use of the stereoscope.

b. Ability to measure depth with a reasonable accuracy by observing and recording measurements of points in a stereomodel.

c. Ability to coordinate eye and muscular control by plotting contours or form lines.

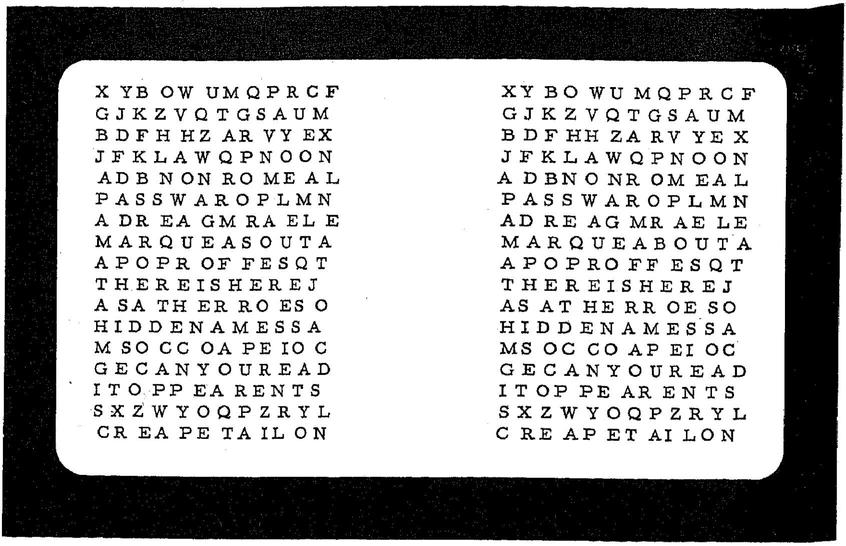
3. Materials Required

a. Stereoscope.
b. Stereograms.
c. Multiplex glasses.
d. Multiplex stereoequipment.
e. Photographs.
f. An oriented stereomodel, having different types of terrain and the best density obtainable for stereoscopic view.
g. Manuscript with preselected points plotted.

4. Procedure

a. Step 1. The candidate is assigned to a multiplex booth provided for giving an eye test. The individual is given a stereoscope and two stereograms (fig. 35) with oral instructions pertaining to the use of the stereoscope and the method for solving the stereograms.

b. Step 2. In 1, figure 35, the two sections of letters in the stereogram should be viewed with the stereoscope. The candidate should adjust the stereoscope until the letters in both sections are superimposed. Then some of the letters will appear to float above the plane formed by the paper and other letters. The floating letters



1 **What is the hidden message?**

Figure 35. Stereograms.

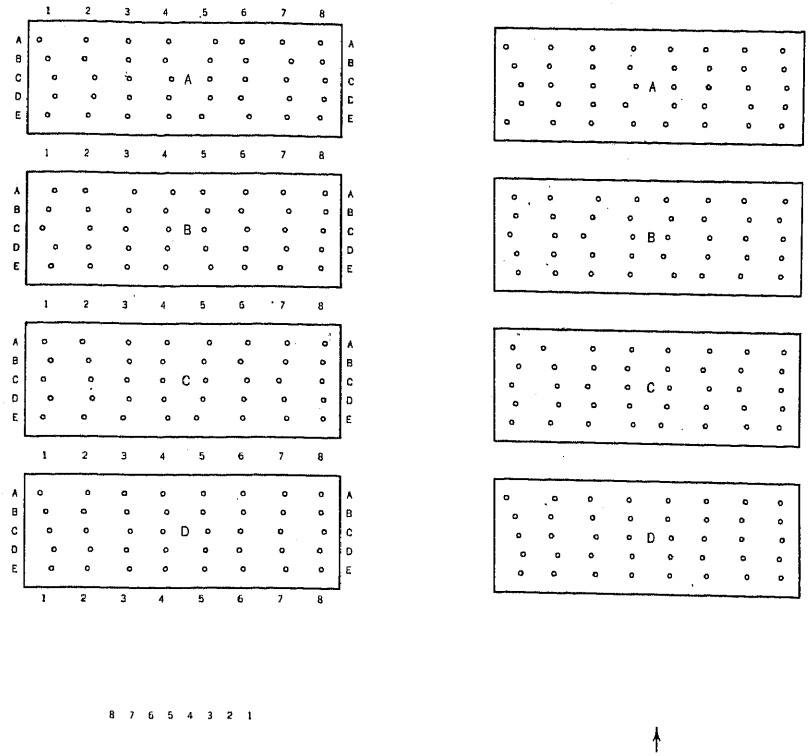
spell a message which should be written down and given to the instructor.

c. Step 3. In 2, figure 35, the individual views each row (A, B, C, and D) separately and records the number of each circle that appears to float above the plane formed by the paper and the other circles.

d. Step 4. The candidate is then given an explanation of the parts of the multiplex equipment which he will need to use in the other tests. The instructor should demonstrate the principles and the use of the floating dot. When the instructor is satisfied that the individual has a complete understanding of these principles, he shows him the position of the preselected points which are marked on the manuscript. Time should be allowed for practice in reading these positions until the individual feels he is ready to record his measurements. He then reads and records the elevation of each of the points and gives them to the instructor after each set of readings. This is done three times to determine the accuracy and consistency of the individual's observations.

e. Step 5. The candidate is now ready for the part of the test involving contours. He should first understand that a contour is an imaginary line of the earth's surface, connecting points of equal elevation. The instructor should plot a contour, explaining the principle of keeping the floating dot in contact with the ground. Then he observes and assists as the candidate plots the same con-

(Lens separation 2.4 inches)



2 Floating-circles stereogram text

Figure 35—Continued.

tour. The candidate is now asked to plot approximately two inches of a contour, at a given elevation, on both sides of a ridge. When this is completed, the tracing table is raised or lowered 2.0 millimeters and the individual plots another contour on both sides of the ridge.

f. Step 6. When the tests are completed, the instructor checks each part and records the results on the evaluation card (fig. 36).

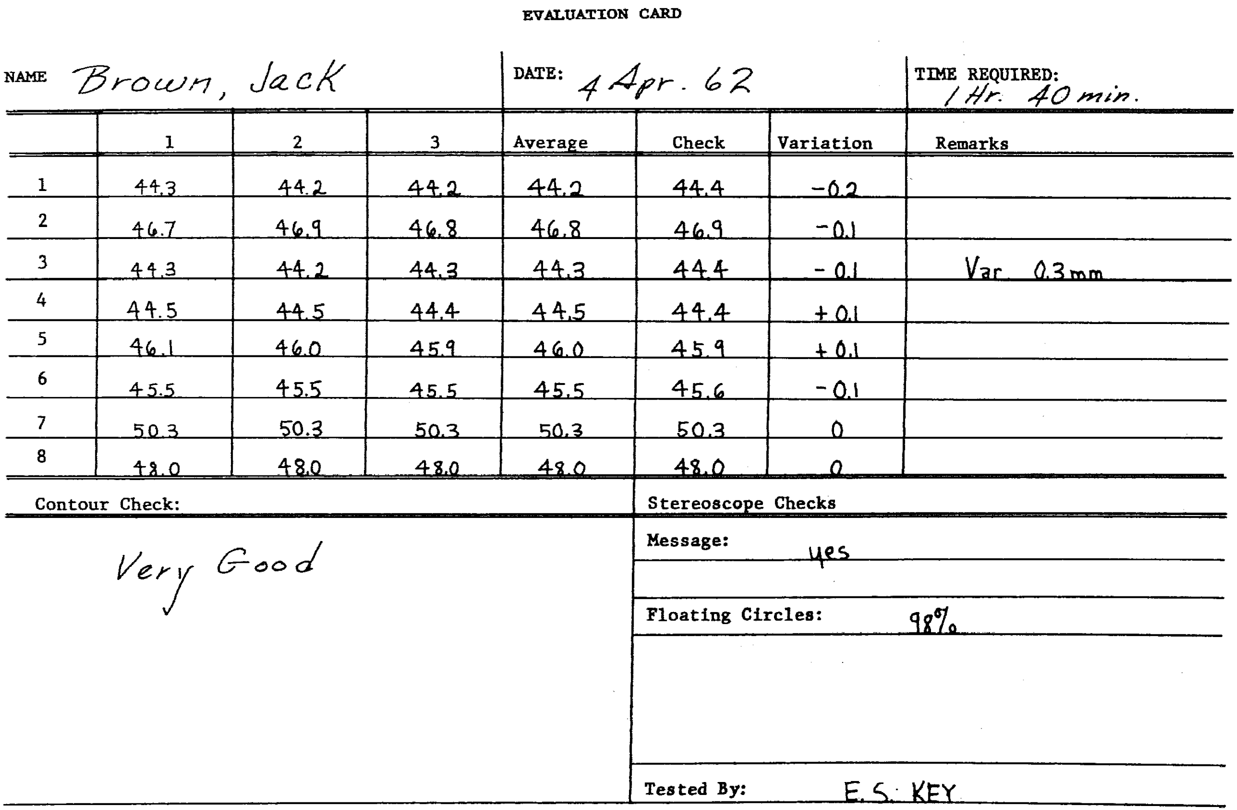
5. Evaluation

a. Stereograms. The answers are checked by using an answer list provided for this purpose. The stereogram test is graded on a percentage basis; 90 percent is considered an acceptable score.

b. Reading and Recording Measurements. The instructor reads and records the measurement for each point on the evaluation card. This test is evaluated by observing the variance between the instructor's reading and the average of the three readings of the candidate. This is done for each of the points, and the candidate is rated by totaling the maximum plus and maximum minus variance. To be acceptable for multiplex training, the sum of the variances should not exceed 0.5 millimeter.

c. Contouring. When the candidate has plotted the two contours, 2.0 millimeters apart, the instructor checks them by plotting the 1.0 millimeter contour that falls between the two. The contour test is graded as poor, fair, good, or very good. This test is a coordination exercise rather than a measurement test.

d. Evaluation Card. If the evaluation card shows that the candidate's stereoscopic vision is unsatisfactory for immediate multiplex training, additional training may be given to improve his perception of depth. Daily practice in fusing the stereograms will aid in increasing the individual's power of fusion. The eyes should be rested if they become tired.



EVALUATION CARD

NAME Brown, Jack | DATE: 4 Apr. 62 | TIME REQUIRED: 1 Hr. 40 min.

	1	2	3	Average	Check	Variation	Remarks
1	44.3	44.2	44.2	44.2	44.4	-0.2	
2	46.7	46.9	46.8	46.8	46.9	-0.1	
3	44.3	44.2	44.3	44.3	44.4	-0.1	Var 0.3mm
4	44.5	44.5	44.4	44.5	44.4	+0.1	
5	46.1	46.0	45.9	46.0	45.9	+0.1	
6	45.5	45.5	45.5	45.5	45.6	-0.1	
7	50.3	50.3	50.3	50.3	50.3	0	
8	48.0	48.0	48.0	48.0	48.0	0	

Contour Check:

Very Good

Stereoscope Checks

Message: yes

Floating Circles: 98%

Tested By: E.S. KEY

Figure 36. Evaluation card.

APPENDIX V

MULTIPLEX SECTION FLOOR PLAN

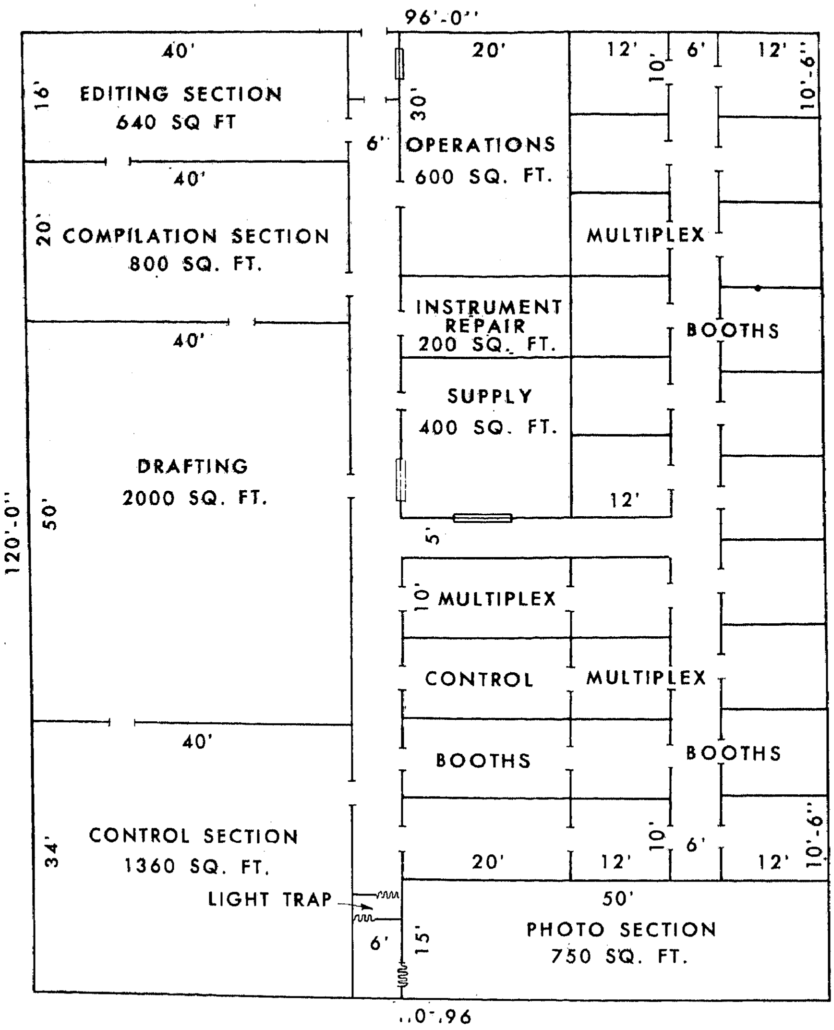


Figure 37. Ideal floor plan for multiplex section.

APPENDIX VI

ADJUSTMENT OF OBLIQUE EQUIPMENT

1. Additional Equipment

In converting vertical multiplex equipment to use oblique photography, additional equipment will be needed in order to reposition the bar in such a way that full use of the entire projection distance is made available during operation. This additional equipment consists of:

a. One tilt bar assembly and one condenser clamp for each projector.

b. Two multiplex projector packing cases to each multiplex bar.

c. One short length of wood, approximately 18 inches long, 4 inches wide, and 4 inches thick, for each packing case.

2. Converting From Vertical to Oblique

a. Multiplex Projector Packing Cases. Two packing cases are used in lieu of the multiplex table, to hold the two end supports of the multiplex frame. This allows the frame to be positioned *behind* the table. Because the packing cases are not quite high enough, a length of wood is placed on top of each packing case and used as a rest for the foot pads.

b. Multiplex Frame. The multiplex frame is assembled and placed on the packing cases and centered and leveled in this position. Before moving the frame from the table to the packing cases, all projectors are removed from the bar and all electrical circuits and air hoses are disconnected.

c. Multiplex Table. The multiplex table is placed so that it will be directly under and in front of the projectors, and leveled in the usual manner. To facilitate the conversion to oblique, the multiplex table is the last item to be moved and adjusted into place. This will enable the multiplex operator to stand between the table and frame for ready access while converting the projectors.

3. Oblique Projectors

The oblique projector is an adaptation of the standard vertical projector; the modification consists merely of tilting the projector from the vertical by the addition of a tilt bar assembly and a condenser clamp.

a. Condenser Clamp. The condenser clamp is a circular holding device which is secured to the condenser to keep it from falling over when the projector is tilted at extreme angles. After the bar has been placed on the packing cases, replace one projector at a time and convert to oblique. Assemble the condenser clamp to the condenser in the following manner:

(1) With the free swing motion, turn the projector clockwise approximately 100° and lock in this position.

(2) Remove the condenser from the projector body; slide the condenser clamp up from the bottom of the condenser, and replace the condenser on the projector body.

(3) With the wing clips of the condenser clamp facing the operator, adjust the clamp so that the bottoms of the wing clips can be *firmly* swung to a holding position under the projector base lip.

(4) Tighten the clamp to the condenser. Thus, the condenser is fastened and held rigidly in place with the air intake nipple, filters, and the diapositive centering screws, readily available to the operator.

b. Tilt Bar Assembly. The tilt bar assembly is an adjustable device which is secured between the bracket assembly and the projector body, and allows the projector to be tilted 20°, 40°, or 60° from the vertical. Assemble and adjust the tilt bar assembly in the following manner:

(1) Disengage the condenser clamp from the projector base lip by an outward swing of the wing clips, and remove the condenser from the projector body.

(2) Separate the projector body from the bracket assembly by removing the four flat head screw bolts joining them.

(3) Separate the tilt bar assembly by removing the wing nuts and bolts.

(4) Fasten the tilt bar to the projector body by replacing two of the four flat head screw bolts removed in (2) above and, in addition, use two of the four round head screw bolts furnished with the tilt bar assembly.

(5) Fasten the angle rack to the bracket assembly in the same manner as in (4) above.

(6) Connect and adjust the projector body to the bracket assembly at the required degree of tilt, with the two bolts and wing nuts furnished.

(7) Replace the condenser over the projector body and engage the condenser clamp with the projector base lip by an inward swing of the wing clips.

4. Projection Distance

The optimum projection distance for oblique multiplex is the same as with vertical equipment—360-mm. This distance is measured from the center of the lens to the platen surface when the projector is in the middle of its Z range and the platen is in the middle of its range directly over the principal point of the projection image. It becomes rather difficult to obtain a correct measurement because of the angle of the projector. Therefore, it has been determined that the *vertical* distance from the projector boss to the platen is 235-mm. When the projector is tilted 60°, this distance of 235-mm then is used to obtain the proper optimum projection distance for 60° oblique models.

APPENDIX VII

MISCELLANEOUS EQUIPMENT

1. Projector Levels

The wide-angle projector level (fig. 38) is designed for use with the wide-angle projectors for the purpose of measuring the angles of tip and tilt at which the projector has been set and for adjusting it to a predetermined inclination. It consists of a base, which may be attached to the projector in place of the condenser, and above it a casting carrying a bubble level and an observing microscope. The base has a swinging arm with a slot to engage the boss on the projector for the purpose of securing proper orientation of the projector level with respect to the projector. The swinging arm is held away from the projector when not in use by means of a catch. When released from the catch, the arm is held against the projector bracket by the action of a coil spring. The casting may be rotated about the base so that the crossline in the observing microscope may be alined with the collimation marks on the diapositive and locked in the desired position by means of the clamp screw. The swing of the diapositive with respect to the projector may then be read on the graduated circle on the rotating portion of the instrument. Direct readings to 15 minutes of arc may be made with the aid of the vernier attached to the base. The level is mounted on an arm attached at one end of a horizontal bearing; about this bearing the arm can be caused to rotate in a plane perpendicular to the base of the instrument by the action of an adjusting screw working against a spring plunger. At the other end is a scale and vernier graduated to read angles up to 10 above and below the horizontal, with a least reading of 5 minutes of arc. The instrument has the same weight as the condenser. The construction of the normal projector level is similar to that of the wide-angle projector level except that no provision is made for orienting it with respect to the projector or the diapositive. The angle of inclination may be read below the horizontal up to 10°.

2. Height Gage

The height gage (fig. 39) is used for measuring the height of the projector above any datum plane. The height gage has an English and metric measure, 1½ inches to 24 inches and 40-mm to 60-cm outside of the jaws, and can be read to 0.001 inch and 1/50-mm by vernier. There are two indicators attached to the height gage; the bottom one to be placed on the tracing table platen and the upper one on top of the boss on the projector. The correct

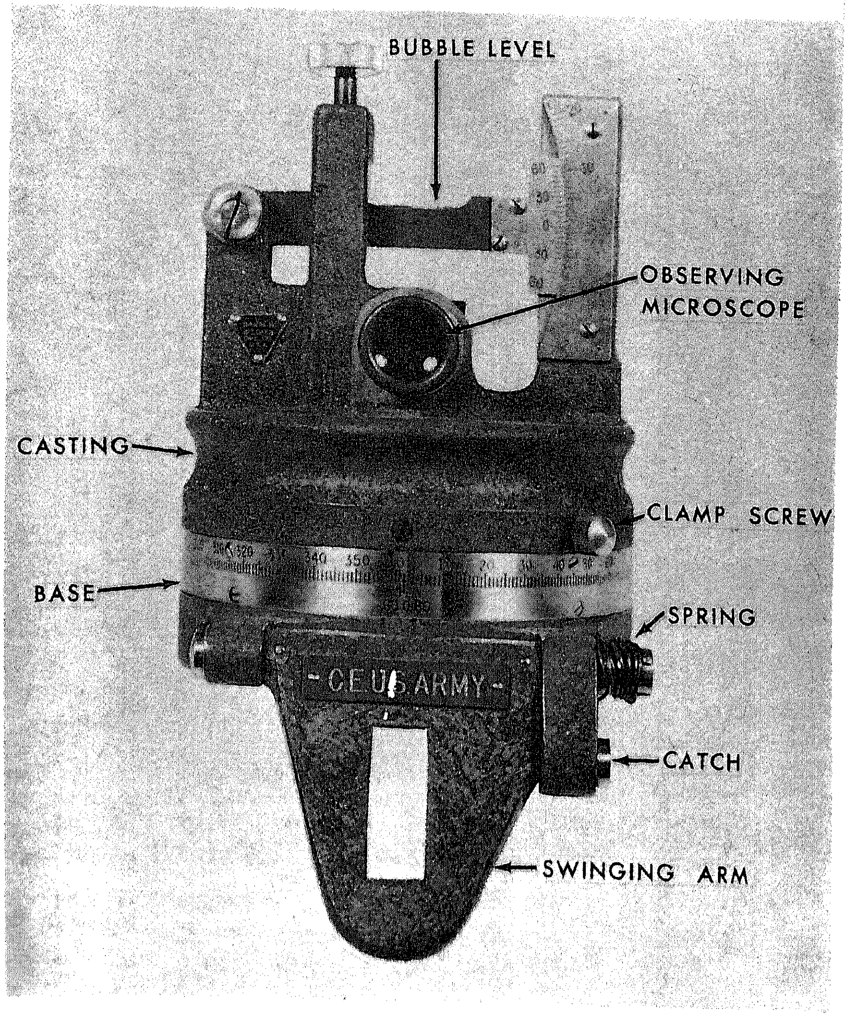


Figure 38. Wide-angle projector level.

height from the boss to the platen is read direct and the lower reading subtracted from the upper to resolve the projection distance.

3. Nadirscope

The nadirscope (fig. 40) is used to find the nadir (plumb) point vertically below each multiplex projector lens. The instrument consists of a finely etched cross suspended directly over the dot of light in the tracing table platen. Moving the table around until the dot of light is centered in the shadow of the cross brings the

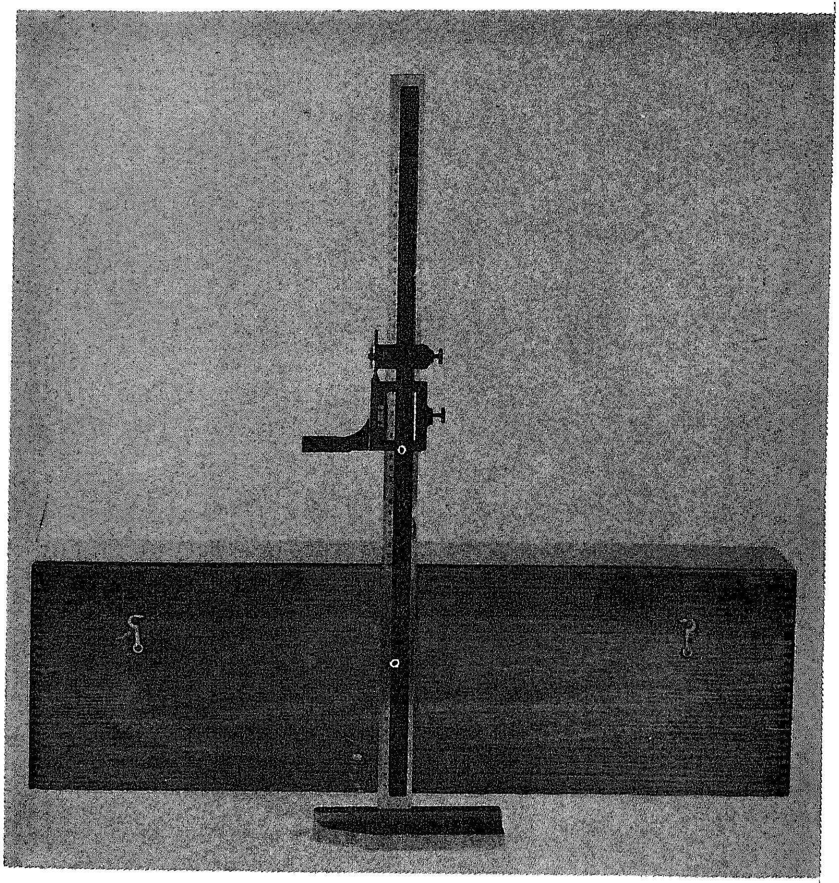


Figure 39. Height gage.

table directly under the projector lens and permits the nadir point to be marked by dropping the pencil point. The instrument may also be used in leveling an individual projector, since the principal point and nadir point are coincident only when the projector is truly level. In this operation, the tracing table is first set at the projector nadir point and the tip and tilt screws adjusted until the principal point is centered over the dot of light.

a. Attaching the Nadirscope. In attaching the nadirscope to the tracing table, a binding of the sliding parts may sometimes be encountered as a result of variation in the spacing of the vertical columns. The use of thin shims will ordinarily relieve this situation. Once in position, it can be left in place since the cross-hairs slide out of the way when not needed (fig. 41).

b. Locking and Centering. When the nadirscope is in use, the frame is locked into position with the knurled screw and the

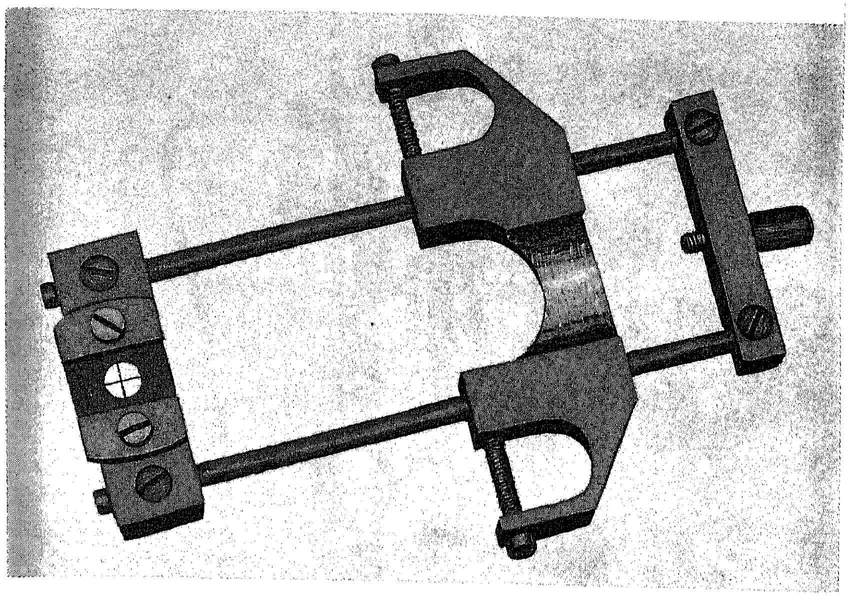


Figure 40. Nadirscope.

tracing table platen lowered so as to give the greatest possible distance between crosshairs and shadow. It is also necessary that the centering be checked from time to time to insure that verticality of pencil, point of light, and crosshairs remains true. Any necessary adjustment is started by making sure that the pencil is exactly centered under the dot of light with the platen at its lowest position.

c. Plotting of Nadir Point. The nadir point of a projector is now plotted. The entire tracing table is then rotated through 180° and the nadir point is again plotted. Any displacement between the two plotted points represents twice the centering error and must be removed by means of the adjusting screws of the nadirscope. Exact centering is achieved by repeating the procedure until coincidence is obtained. As a final check, the crosshairs should be moved out of position and then back and the test rerun to be sure that the frame always returns to the same position.

d. Application of Nadirscope. The nadirscope is employed in application to BZ curves (SHORAN), to level a projector, and in determining x tilt and y tilt angles in a diapositive.

(1) An application of the BZ curve is its use in finding the displacement between the true photo plumb point and the nadir point directly beneath the projector lens as indicated by the multiplex nadirscope. Where the models

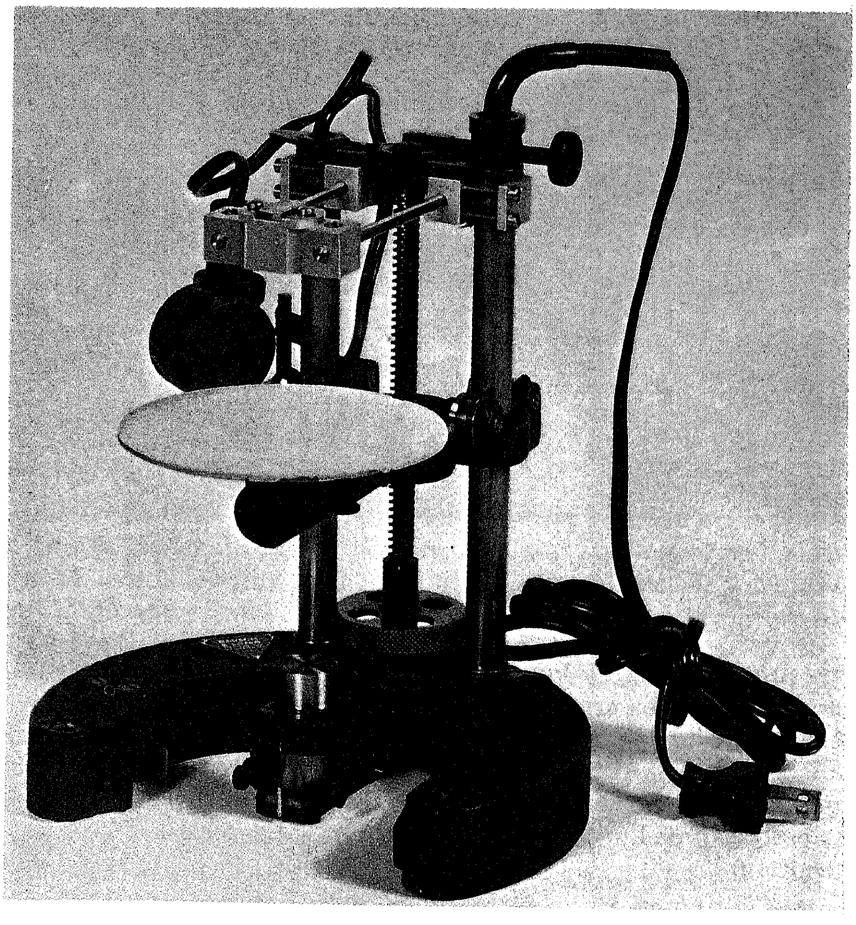


Figure 41. Nadirscope attached.

can be individually oriented, these two points are the same. In strip orientation, however, the fall-off in projector height also introduces a "false tip" which must be analyzed and corrected in the course of scaling to Shoran control. The false tip in any projector is the angle between a horizontal line and a tangent to the curve at the point representing the projector. The displacement between the true photo plumb point and the indicated projector nadir point is equal to the projection distance times the tangent of the angle of false tip. In practice, the projection distance is found by measuring the vertical distance from the model surface at the indicated nadir point to the top of the projector boss, and then subtracting the distance from the emergent node of the lens to the top of the boss. In this operation, the height of the top of the boss above the emergent node may be considered a constant of 3.89-mm for all Army projectors. The tangent of the false tip angle is merely the slope of the line tangent to the curve expressed as a ratio of ordinates to abscissas.

(2) The nadirscope may also be used to level a single projector, since the principal point and nadir point are coincident when the projector is truly level. This is an important operation in the determination of true flying heights by multiplex methods.

(3) By analysis of the relation between the nadir point and principal point, the x tilt and y tilt angles of a diapositive may be determined.

APPENDIX VIII

SUPPLEMENTAL PHOTOG

1. To reduce the overall cost of the map con
photographic coverage of a mapping project
at the highest possible altitude which will s
and vertical map accuracy requirements usi
struments. High altitude photography minim
for geodetic control and reduces the number o
tion. It also reduces the ability to photoident
Large scale supplemental photography can
pensate for this limitation in identifying feat
photography.

2. When the scale of basic mapping photog
mapped at large or medium scales is smaller
field classification survey is not performed, i
procure 12-inch focal length supplemental
ever a field classification survey is performe
tography is not necessary except for highly
areas being mapped at large scales.

3. Normallv. the supplemental photograp
focal length cameras of
the split vertical position or with
[illegible] a 9- x 18-inch format mounted i
The basic mapping and supplemental photog
posed simultaneously.

4. A study of long focal length photograph
focal length of the camera is increased at a c
ground detail that may be identified also incr
that if the focal length is greatly increased,
that may be identified will approach the am
that can be obtained by a complete field classifi
results could never be obtained). The cost i
mapping, but does not provide as satisfacto
plemental photography is more expensive th
on 1:250,000 scale mapping and will not give
fore, the cost is justified for large scale ma
classification, where the basic photography
smaller.

5. It has been further determined by per
fication, using both 6-inch and 12-inch focal
exposed simultaneously, that approximately 5
could be identified with the use of the 12-inch

raphy as opposed to the 6-inch viewed at the smaller scale. Therefore, supplemental photography to accompany basic 6 inch focal length high altitude photography is vital at altitudes over 15,000 feet for identification of map detail. The 12-inch focal length photography is adequate for altitudes up to about 30,000 feet, but the focal length should be increased at altitudes above 30,000 feet. This supplemental photography should cover the same areas covered by the basic photography, preferably exposed simultaneously with the basic coverage.

6. The criteria for determining specifically when supplemental photography is required are shown in table V.

Table V. Supplemental Aerial Photographic Requirements

(When the scale of the basic mapping photography is smaller than 1:30,000)

	Map scales					
	1:25,000		1:50,000		1:250,000	
Typical areas and type of terrain	W/ field classification	W/o field classification	W/ field classification	W/o field classification	W/ field classification	W/o field classification
1. Highly developed domestic and foreign	Yes	Yes	Yes	Yes	No	Yes
2. Coastal areas	Yes	Yes	Yes	Yes	No	Yes
3. Desert—foreign	No	Yes	No	Yes	No	No
4. Developed valley areas	No	Yes	No	Yes	No	Yes
5. Rain forest	No	No	No	No	No	No
6. Plains areas domestic	No	Yes	No	Yes	No	Yes
7. Plains areas foreign	No	Yes	No	Yes	No	Yes

Note. When a field completion survey is planned, the requirement for supplemental photography will be the same as when no field classification survey is performed.

APPENDIX IX
MULTIPLEX VAN SECTION

1. Introduction

The Multiplex van section (fig. 42) consists of an Engineer expansible van body mounted on a standard 2½ ton, 190-inch wheelbase, M46 truck chassis, outfitted with multiplex equipment. The van also contains photographic-laboratory equipment. It is air transportable, and requires no suppression treatment for radio interference.

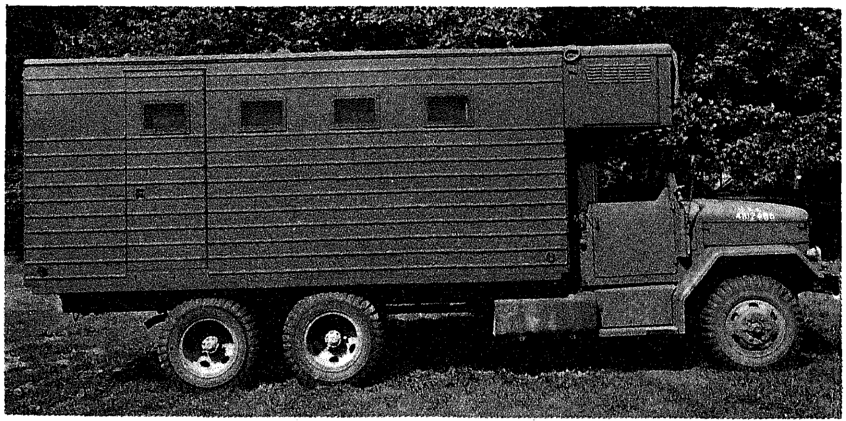


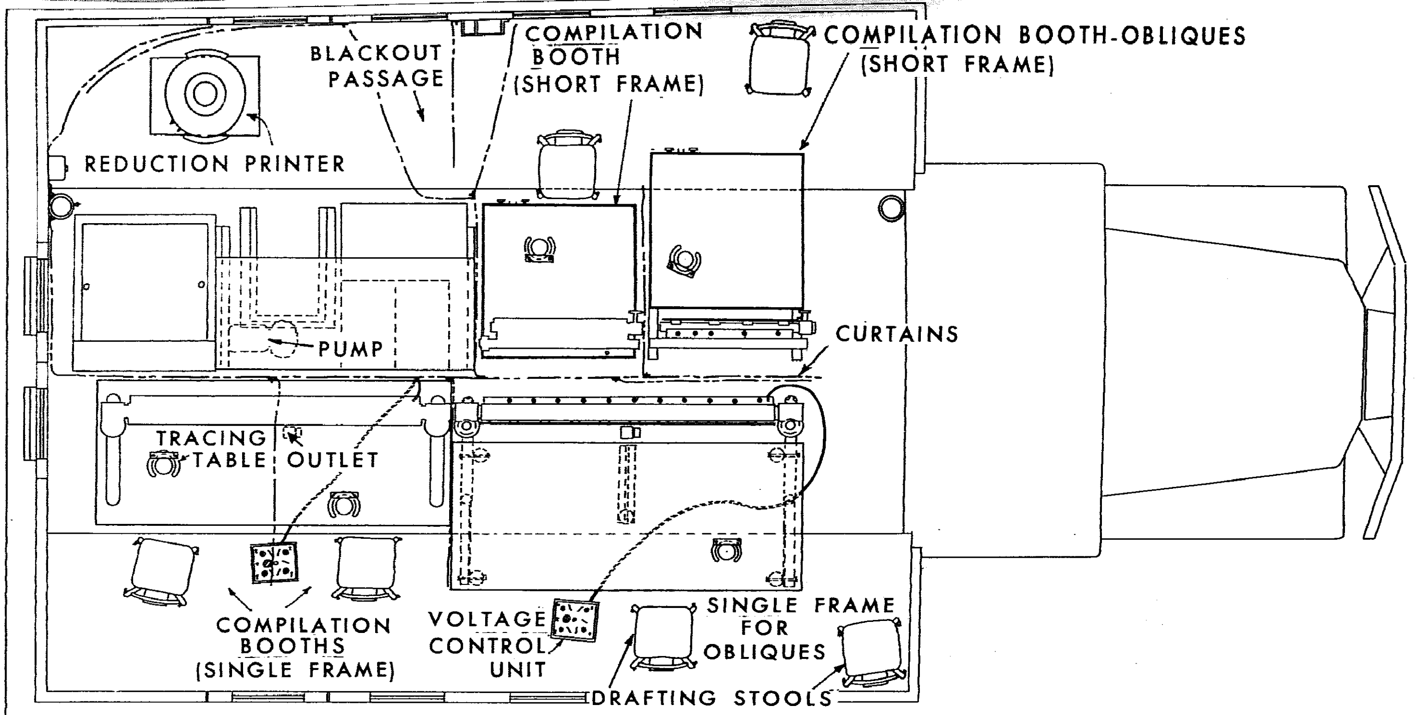
Figure 42. Multiplex van section.

2. Description

The van body is constructed with a steel frame, aluminum and plywood floor, roof, and sides, and fiberglass insulation. Overall length including the truck is 343 inches; width retracted 96 inches; width expanded 168 inches; and height 132 inches. Interior heating is provided by two gasoline-burner type heaters. Cooling is accomplished by an 18,000 BTU per hour air conditioner. The electrical system is wired for a 120/209-volt, 3-phase, 4-wire power source. Power is normally supplied by a trailer-mounted gasoline-driven generator connected to an inlet receptacle at the rear of the van.

3. Interior

The Multiplex van section (fig. 43) is divided into three work compartments separated by canvas curtains. The right half constitutes the control extension subsection, the left front portion


BLACKOUT PASSAGE
COMPILATION BOOTH (SHORT FRAME)
COMPILATION BOOTH-OBLIQUES (SHORT FRAME)
REDUCTION PRINTER
PUMP
CURTAINS
TRACING TABLE
OUTLET
COMPILATION BOOTHS (SINGLE FRAME)
VOLTAGE CONTROL UNIT
SINGLE FRAME FOR OBLIQUES
DRAFTING STOOLS

NOTE: MULTIPLEX PROJECTORS ARE NOT SHOWN

Figure 43. Multiplex van section with equipment in working position (plan view).

comprises the compilation unit, and the rear left portion is used as a photo lab. The permanently installed equipment is located in the solid portion of the van and work space is provided by the expanded floor sections.

4. Control Extension

The part of the van equipped for control extension operations is furnished with a standard double multiplex frame consisting of two matched standard single frames and a double frame adaptor. The double frame, described more fully below, is capable of holding 18 projectors. The two single frames can be used individually, each capable of holding nine multiplex projectors. The control extension subsection is also furnished with 2 multiplex tables, 18 projectors, 2 voltage control units, 1 storage cabinet with multiplex accessories, drafting equipment, and supplies. This subsection can also be used effectively for multiplex compilation by dividing it with curtains into four individual booths.

a. Double-Frame. The double multiplex frame requires no central support and is formed by removing one end support from each of two single frames and joining the single frames in the center with a double frame adapter. Before transit, each single unit is secured to the table top by tiedowns consisting of cushion blocks,
nch cables, and locking nuts. The multiplex
ssue items measuring 3 ft by 7 ft, with a rein-
m top supported on five steel legs. The floor
make it possible to slide the table forward 15 inches
and bolt it in the position required for oblique photography compilation.

b. Multiplex Projectors. The projectors used in this van are standard equipment, self cooling, and require no blowers. They are stored three projectors, with accessories, to a case and are transported in the cargo trailer.

c. Voltage Control Units. The voltage control units are standard items, dial type, and consist of a control box and transformer. The units are mounted on individual caster-type dollies which can be secured to the floor and stored under one of the multiplex tables during transit.

d. Multiplex Supply Cabinet. The supply cabinet is a metal 6-drawer-type unit, 24½ inches wide, 24½ inches long, and 25½ inches high. It is permanently installed on the floor under the rear multiplex table.

5. Photo Lab

The subsection used as a photo lab is a fully equipped darkroom for printing, processing, and indexing multiplex diapositive plates.

The lab contains a standard multiplex reduction printer and accessories, a photographic temperature-controlled sink, a diapositive wash tank, water storage tank, water pump, diapositive storage cabinet, storage cabinet for photographic supplies and accessories, and two photographic safelights.

a. Multiplex Reduction Printer. The multiplex diapositive plate reduction printer is mounted on an all-metal dolly with rubber-tired casters and is moved onto the expanded floor section when in use. During transit it is stored between the sink and the supply cabinet.

b. Photographic Processing Sink. The processing sink is temperature controlled and consists of a stainless steel "sink top" and a supporting all-steel cabinet which houses the temperature control unit, a heat exchanger, a water circulating pump, and the required plumbing. The temperature control unit is capable of automatically heating or cooling 1 to 1½ inches of water in the sink to the required temperature of 68° F. or any temperature in the 50° F. to 90° F. range. The sink is filled through an intake line by proper regulation of the three-way valves on this line. The sink water pump circulates the water from the right side of the sink to the pump, thence to a heat exchange drum, temperature control unit, and back to the sink from the opposite side.

c. Diapositive Wash Tank. The wash tank is mounted over the sink and drains into the sink drainage system. After passing through the coils of the heat exchanger, water enters the tank through a perforated ⅞-inch feed pipe.

d. Water Storage Tank. Water for the system is stored in a gravity feed type, 100-gallon capacity tank. The tank is equipped with two baffle plates, a waterlevel gage, an overflow pipe, and a drip pan to catch condensate.

e. Diapositive Storage Cabinet. Storage space for diapositive plates and data is provided by a small 2-drawer wide, 1-drawer high metal cabinet situated on top of the photographic storage cabinet. One drawer is partitioned to accommodate processed diapositive plates, and the second drawer is used for filing photo lab records and data.

f. Photographic Storage Cabinet. A metal cabinet with adjustable shelves and sliding doors is used to store photo lab supplies. It has a ¾-inch, plastic covered, plywood top for use as a working surface.

g. Safelights. Two photographic safelight frames are installed over the two fluorescent light fixtures in the ceiling of the van directly over the temperature controlled sink and photographic storage cabinet. These frames are designed for use with the standard photo safelight filter and are equipped with a blockout disk which provides white light when rotated to a position that exposes an open area on the bottom of the frame.

6. Map Compilation

The third and last portion of the van is used for map compilation. It is equipped with two 32-inch multiplex frames consisting of a table, short frame, and voltage control unit. Additional equipment in this unit consists of six multiplex projectors, two multiplex tracing tables, and two drafting stools.

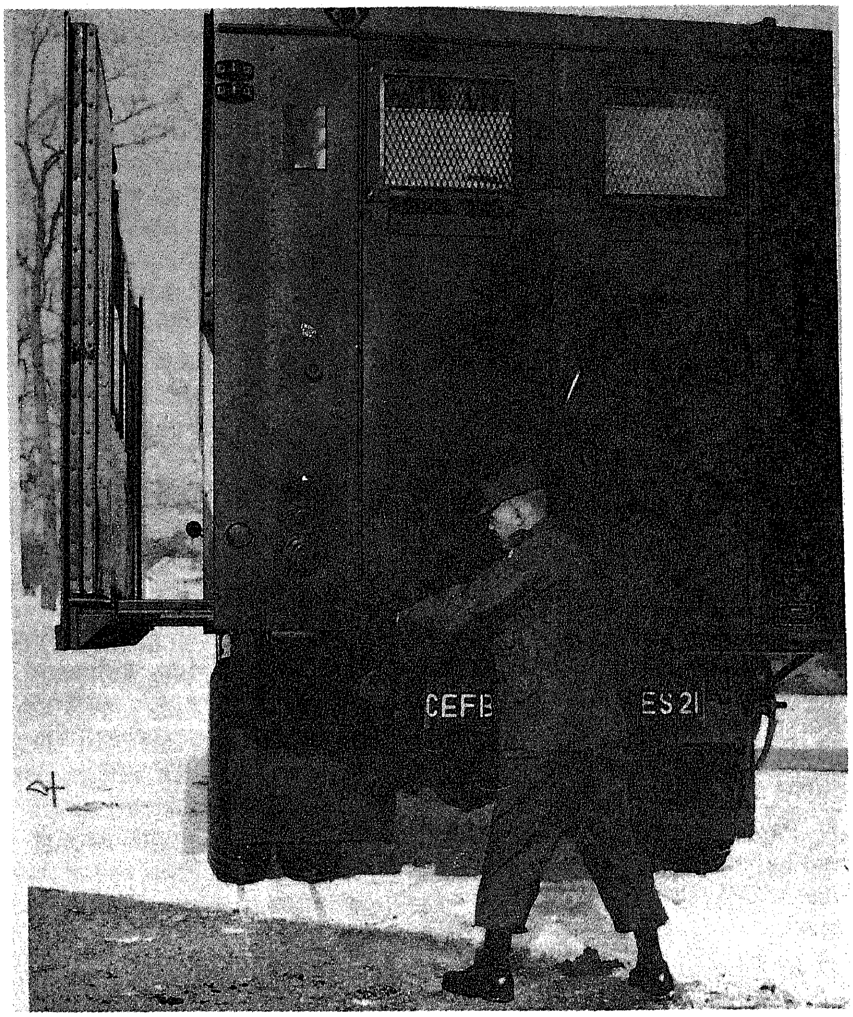


Figure 44. Cranking out the side.

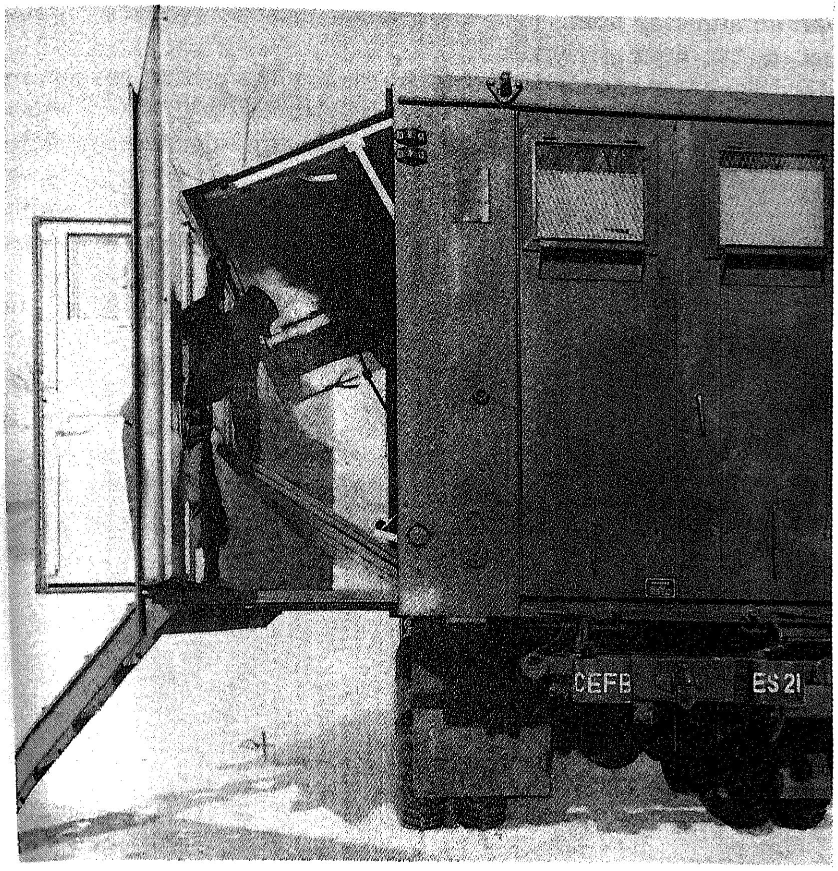


Figure 45. Opening the roof and floor sections.

7. Expansion and Retraction

Only two tools are necessary for the operation of the van. One of these is a crank for cranking the expansible sides in and out. The other is a locking tool used for locking and unlocking the sides. Expansion of one side of the van is accomplished as described below.

a. Two locking studs (small square studs on the side of the van) are rotated 90° with the locking tool to unlock the side.

b. The crank is fitted on the shaft at the rear of the van and the side is cranked out to its limit (fig. 44).

c. End panels are swung out.

d. The third locking stud (in the surface exposed when the side is cranked out) is rotated to the unlocked position. The roof section is raised and the floor section is lowered (fig. 45) by pulling out on either or both. (The sections are interconnected so as one moves, the other moves also.)

e. The three supporting hooks just below the ceiling are swung out from the expanded wall and at right angles to it.

f. The end panels are swung into their proper positions and the guide bolts are inserted into the receivers.

g. The side is cranked in as far as it will go and the draw bolts in the ceiling are attached to the supporting hooks, and drawn tight.

h. This completes the expansion procedure for one side of the van (fig. 46); the other side is expanded in exactly the same manner. Retraction of the van is accomplished by reversing the procedure described for expansion.

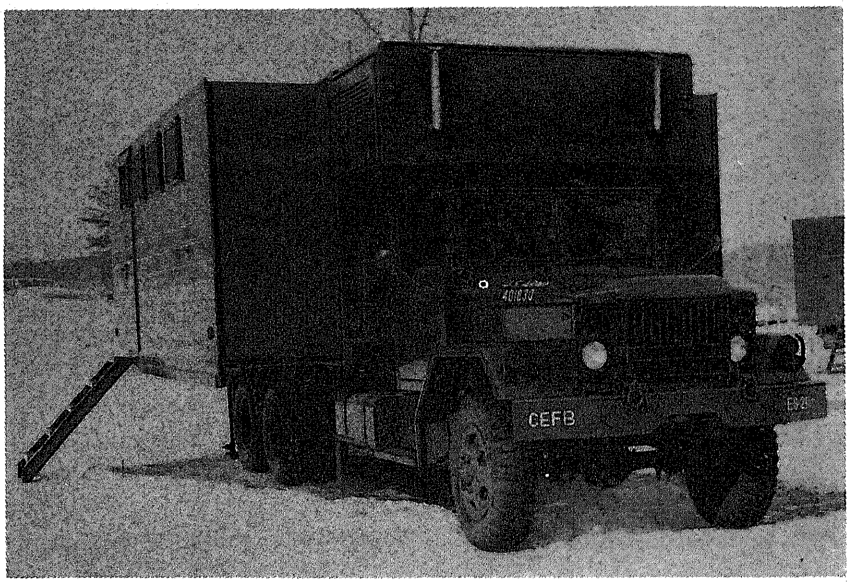


Figure 46. Van expanded.

GLOSSARY

Absolute orientation—See orientation.

Absolute parallax—See parallax.

Accuracy—Degree of conformity with a standard. Accuracy relates to the quality of a result, and is distinguished from precision which relates to the quality or refinement of the operation by which the result is obtained.

Air base—The line joining two air stations or the length of this line. See base line.

Altimeter—An instrument which utilizes relative pressure of the atmosphere to indicate the vertical distance above a specified datum plane.

Altitude—The vertical distance above the datum, usually mean sea level, to an object or point in space.

Anaglyph—A picture printed, or projected, in complementary colors and combining the two images of a stereoscopic pair, and which gives a stereoscopic image when viewed through spectacles having filters of corresponding complementary colors. The same effect can be obtained by using polarized light and filters.

Angle of coverage—The maximum angle subtended at a lens by light rays forming the image.

Azimuth line—A radial line from the principal point, isocenter, or nadir point of a photograph, representing the direction to a similar point on an adjacent photograph in the same line of flight, used extensively in radial triangulation.

Base line—Line connecting the lens nodes of adjacent multiplex projectors. Corresponds to and is a miniature representation of the air base.

Binocular vision—See stereoscopy.

Bridging—The extension and adjustment of photogrammetric surveys betwen bands of ground control.

BZ curve—The curve obtained when a smooth line is drawn through points representing the height and distances along the flight line of several projectors used in a multiplex extension. BZ is the differential change in the relative position of a plotting camera. It is measured parallel to the z axis of the instrument spatial coordinate system.

C factor—The ratio of flight altitude to contour interval which may be compiled with 90 percent of elevations interpolated from the contours accurate to within one-half the contour interval.

Calibrated focal length—See focal length.

Calibration—The act or process of determining certain specific measurements in a camera, or other instrument, for comparison with a standard.

Cantilever extension—The prolongation of a strip of photographs
photogrammetric methods from a controlled area to an area

rt of expressing graphically, by
known physical features of the
uding the works of man and his

glass surfaces have been coated
of such index of refraction as to
reflection. This reflection loss of
it 4 percent per air-glass surface.

lower pressure plate of the re-
egative is oriented. See fiducial

reduction printer to compensate
from the center of an aerial

cting map detail from aerial photo-
it a control network in the prepara-

Complementary colors—Colors which, when added together, such
as by projection, produce white light.

Condenser—A lens or lens system so designed as to concentrat
the illumination from a light source upon a limited area.

Conjugate distances—The corresponding distances of object an
image from a lens. For every position that an object may occup
with respect to a lens, there is a corresponding position for th
image. These distances are called conjugate distances.

Contour—An imaginary line connecting the points on a land sur
face that have the same elevation; also the line representing thi
on a map.

Control—A system of relatively accurate measurements to deter
mine the distances and directions or differences in elevation be
tween points on the earth and upon which depends a system o
lesser accuracy.

Geodetic control—Control which takes into account the size an
shape of the earth, that is, a system of points of known lati
tude, longitude, and elevation.

Ground control—Control obtained by ground surveys as distin
guished from control obtained by photogrammetric methods.

Horizontal control—Control which determines horizontal positions only, as with respect to parallels and meridians, or to other lines of reference.

Multiplex control—Control established from other existing control by bridging or by cantilever extension.

Recovered control—Control previously established from other sources, which can be identified.

Starting control—Control available for the absolute orientation of the first plate pair along a line of flight for which control is to be extended.

Vertical control—Control which determines positions with respect to elevations only.

Coordinates—Linear or angular quantities which designate the position which a point occupies in a given reference frame or system. The distances parallel with the true North-South axis are called the y coordinates and the distances parallel with the true East-West axis are called x coordinates.

Crab—Angle between the edge of a photograph not being parallel to the line of flight.

Cross tilt—Relative tilt between the datum planes of two stereoscopic models formed when a third projection is added to two existing projections.

Culture—Those features of terrain that have been constructed by man such as roads, trails, buildings, and canals; also boundary lines; and all names and legends.

Datum—A reference element, such as a line, or plane, in relation to which the positions of other elements are determined.

Diapositive—Positive print on glass used in projecting a view with a multiplex projector.

Distortion—One of the abberations of a photographic lens which causes images to be relatively displaced from their true position as occurring in nature. This deformation is normally symmetrical about the optical axis of the lens.

Dodging disk—Disk inserted between the lower pressure plate and the diffusing glass of a reduction printer to compensate for other than annular changes in density in an aerial photograph negative. See compensator lens.

Equivalent focal length—See focal length.

Exterior orientation—See orientation.

Fiducial marks—Index marks rigidly connected with the camera lens through the camera body and forming images on the negative which define the principal point of the photograph.

Filter—Any transparent material which absorbs a certain portion of the spectrum.

Floating mark—A mark in the center of the tracing table which is physically raised and lowered within the spatial model to determine the elevation of ground points.

Focal length:

Calibrated focal length—An adjusted value of the equivalent focal length so computed as to distribute the effects of lens distortion over the entire field used in the aerial camera.

Equivalent focal length—The distance measured along the lens axis from the rear nodal point to the plane of best average definition over the entire field in an aerial camera.

Focus—Characteristic of a photographic lens. A lens is said to be in focus when the lens is so placed with respect to the image plane that best definition of the image results.

Forward lap—See overlap.

Horizontal control—See control.

Horizontal parallax—See parallax.

Horizontalization—Leveling of the spatial model, bringing it into agreement with vertical control. Horizontalization is a step in absolute orientation.

Hydrography—The plotting on a hydrographic map of the topography of the shores and banks, the depths of soundings and other desirable details.

ap, such as contours and contour num-
lief. See cartography and planimetry.
—See orientation.

Manuscript—Original completed work of multiplex topographers or compilers. See compilation and topography.

Model—See stereoscopic model.

Multiplex extension—Cantilever extension by means of the multiplex equipment.

Multiplex projector—See projector.

Nadir point—That point at which a vertical line through the perspective center of the camera lens pierces the plane of the photography.

Negative—A sensitized plate or film which has been exposed in a camera and has the lights and shades in inverse order to those of the original subject.

Nodel point—One of two points on the optical axis of a lens (or system of lenses) such that a ray emergent from the second point is parallel to the ray incident at the first. This first nodal point is also referred to as the front nodal point, or incident nodal point, and the second point as the rear nodal point or emergent nodal point. Also called simply node, as front node.

Oblique photography—A photograph taken with the camera axis directed intentionally between the horizontal and the vertical.

Optical axis—The optical axis of a lens is a straight line which passes through the centers of curvature of the lens surfaces. In a compound lens, if the centers of curvature of all the components were to lie in one straight line, this line would be the optical axis of such lens. This exact condition is rarely obtained in practice.

Orientation:

Absolute orientation—Fixes the scale, position and orientation of two or more multiplex projectors with reference to the ground coordinates.

Exterior orientation—A set of quantities which fixes the position of the camera station and the angular orientation of the photograph. Such a set consists of three elements of position and two elements of angular orientation. The position is usually expressed in terms of three rectangular coordinate distances, x, y and z. The elements of angular orientation are essentially the tilt of the photograph perpendicular and the azimuth of the principal plane.

Interior orientation—Centering of the diapositive in a multiplex projector by bringing the principal point of the diapositive into coincidence with the principal point of the projector. Interior orientation is an attempt to duplicate in the projector the cone of rays which was captured by the aerial camera lens at the instant of exposure. See principal point.

Relative orientation—Orientation of one multiplex projector with reference to another to produce the relative relationship of the taking cameras.

Overlap—Amount by which one photograph overlaps the areas covered by another, customarily expressed as percentage. The overlap between aerial photographs in the same flight is distinguished as forward lap, and the overlap between photographs in adjacent parallel flights is called side lap.

Overlay—A record on a transparent medium to be superimposed on another record.

Parallax—The apparent displacement of the position of a body with respect to a reference point, or system, caused by a shift in the point of observation.

Absolute stereoscopic parallax—Considering a pair of truly vertical photographs, of equal principal distances, taken from equal flight altitudes, or a pair of rectified photographs, or a stereoscopic model formed by the multiplex projectors of such photographs, the absolute stereoscopic parallax of a point is the algebraic difference, parallel to the base line, of the distances of the two images from their respective principal points. It is a measure to scale of the height of the image in space.

Residual parallax—Small amounts of y parallax which may remain in the model after relative orientation.

x parallax or horizontal parallax—Synonymous with absolute stereoscopic parallax; also used in multiplex operations to denote the component of distance between two point images in a direction parallel to the vertical plane containing the base line.

y parallax or vertical parallax—The difference of the perpendicular distances of the two images of a point from the vertical plane containing the base line.

Pass point—A point whose horizontal and vertical position is determined in the multiplex model, and which is intended for use after the manner of a ground control point in the orientation of other models, or for maintaining the scale of a strip when passing from model to model in multiplex triangulation.

Perspective center, perspective point—The point of origin of a bundle of perspective rays. In a survey photograph the rear node of the lens is the perspective center of the photograph and the front node of the lens is the perspective center of the object.

Photogrammetry—The science and art of obtaining reliable measurements from photographs.

Photograph—A general term for a positive or negative picture made by a camera on plate, film, or other medium.

Picture point—A point, the exact location of which can be readily identified on the aerial photographs used in photomapping.

Planimetry—Parts of a map which represent everything except relief, that is, works of man and natural features such as woods and waters.

Plate pair—See stereoscopic pair.

Plotting scale—The scale of the multiplex model or the scale at which the map is compiled.

Principal distance—In the multiplex projector, the distance from the rear node of the lens to the apparent plane of the diapositive or the physical distance from the rear node to the top of the stage glass corrected for the thickness of the stage glass. In general, it is the perpendicular distance from the perspective center to the plane of the negative photograph, or diapositive.

Principal point—Foot of the perpendicular from the inner node of the lens to the focal plane of the camera (projector).

Print—A photographic copy made by projection or contact printing from a photographic negative or from a transparent drawing as in blue printing.

Projection distance—Distance from the front node of the lens to the plane of projection.

Stereoscopic pair—Two photographs of the same area taken from different camera stations in such a manner that a portion of the area appears on both photographs.

Stereoscopic triplet—Two successive stereograms or stereoscopic pairs in the same flight or strip.

Stereoscopic vision—See stereoscopy.

Stereoscopy—The science and art which deals with steroscopic effects and the methods by which they are produced.

Binocular vision—Simultaneous vision with both eyes.

Stereogram—A stereoscopic pair of photographs or drawings tical position of the features represented; distinguished from

Stereoscopic fusion—That mental process which combines the two perspective images on the retinas of eyes in such a manner as to give a mental impression of a three-dimensional model.

Stereoscopic vision—That particular application of binocular vision which enables the observer to view an object or two different perspectives of an object (as two photographs taken from different camera stations) so as to obtain a mental impression of a three-dimensional model.

Swing—Rotation of a multiplex projector around its vertical axis. Rotation of a photograph in its own plane around the photograph perpendicular.

Tilt—The angle between the plane of the photograph and the horizontal plane normal to the plumbline. See x tilt and y tilt.

Topography—Natural configuration of the surface of the ground, including relief, woods, and waters.

Topographic map—A map which presents the horizontal and vertical position ofthef eatures represented; distinguished from the planimetric map by the addition of relief in measurable form.

Tracing table—Piece of multiplex equipment used for viewing the stereoscopic model, measuring the elevations in that model, and compiling the detail on a map plot.

Transverse axis—The axis of rotation for which there is no displacement in the projection plane of an image in the diapositive plane when the lens is rotated. The transverse axis intersects the optical axis at a point through which passes the line joining an object and its corresponding projected image. The transverse axis is not a fixed point in a lens; its location is dependent upon the magnification.

Vertical control—See control.

Vertical photograph—An aerial photograph made with the camera axis as nearly vertical as practicable in an aircraft.

Wide angle lens—A photographic lens having an unusually large angular field. There is no definite division point between an ordinary and a wide angle lens, but, in general, a wide angle lens has an angular field of greater than 80°.

x motion—Movement of a multiplex projector along the multiplex base bar.

x parallax—See parallax.

x tilt—Rotation of a multiplex projector around the *x* axis, or that component of tilt in a photograph which is perpendicular to the line of flight.

y motion—Movement of a multiplex projector along a line perpendicular to the multiplex base bar.

y parallax—See parallax.

y tilt—Rotation of a multiplex projector about the *y* axis, or that component of tilt in a photograph which is parallel to the line of flight.

z motion—Movement of multiplex projector in a vertical direction.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1962—610523